A RUDIMENTARY TREATISE

ON

CLOCKS AND WATCHES,

AND

BELLS;

WITH A FULL ACCOUNT OF THE

WESTMINSTER CLOCK AND BELLS.

BY

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CONTENTS OF THIS BOOK.

I DEEPLY regret the necessity of making a correction of many pages of this book. The person there spoken of as 'the present Mr. Dent' is present no longer, having died on the 25th of April. His name was formerly Frederick Rippon, and he changed it by desire of his relative, Mr. E. J. Dent, on succeeding to the principal part of his business in 1853. His reserved habits prevented his great skill and scientific acquirements from being as well known as they deserved. They were by no means confined to his own art. I scarcely ever asked him a scientific question on which he could not either give me information at once, or tell me where to find it. It will naturally be expected that I should say who succeeds him in the business of those now celebrated shops at 61 Strand, and 34 Royal Exchange. But I cannot do so yet; inasmuch as the will which he had made (after his wife's death) leaving his property to various friends and connexions for whom he was known to have great regard, and making provision for carrying on the business, was found to have been *burnt* shortly before his death, and not by his own hand, under circumstances so suspicious, that it would be the obvious duty of the executor whom he had appointed to have them rigidly investigated, even if he had no interest in it; and they seem likely to form the subject of a very remarkable 'will cause.' It will soon be known that I am that executor, as I had been before, jointly with him, to the first Mr. Dent. My acquaintance with them was at first only horological, but grew into great intimacy and esteem for them both.

E. B. D.

33, QUEEN ANNE STREET;
July, 1860.

ON THE MEASURES OF TIME.

INTRODUCTION.

INSTEAD of writing a preface afterwards, I will say the little I have to say by way of introduction here.

When this book first came out in 1850 there was nothing of the kind in existence; and so low was the state of horological literature in England, that Reid's old treatise on clockwork, a mere clockmaker's book of the last century, a great part of which had become obsolete, was republished, I think, without any alteration, about the same time. The want of such a book as this has been amply proved by the sale of nearly 7000 copies of the first edition, besides smaller numbers of two subsequent ones, which came to be published by a different publisher, thus: In 1854, Messrs. Black of Edinburgh, the publishers of the new (8th) edition of the *Encyclopædia Britannica,* asked Mr. Dent * to revise the

* It will save trouble to explain at once that, whenever I mention Mr. Dent, I mean either the late Mr. E. J. Dent, who died in 1853, after raising himself from the position of a tallowchandler's apprentice to that of the first horologist in the world, or else the present Mr. Frederick Dent, a gentleman of equal scientific knowledge, who succeeded him in his clock

old article on clockmaking for them, which had been originally written by that same Mr. Reid, a celebrated clockmaker in Edinburgh, and was the foundation of his book. He replied that the article in the last edition was quite behind the science of the age, and ought to be entirely rewritten; and the result was, that I wrote a new one; which was also published from the same type in a small volume in 1855. It was in fact an abridged edition of the original *Rudimentary Treatise*, with the addition of such new matter as had arisen in that period of five years since the first edition, which included the Great Exhibition of 1851.

In 1857 Messrs. Black published a new and enlarged edition of that book, under the title of *Clocks and Locks*, because it contained also the article on locks which I had written in the mean time for the Encyclopædia, with the account of the Westminster clock, carried up to the end of 1856. Therefore, although no 2nd or 3rd editions have ever appeared in Mr. Weale's series under the name of a *Rudimentary Treatise on Clocks*, this is in reality the 4th edition that has been issued within ten years. From the large number which it is intended to print now, it is not likely that a 5th will be required for a good while, and therefore I shall do all I can to make this as complete as possible for the thing which it professes to be.

First, I mean to re-write the book entirely. In the course of ten years, any book on practical science must

factory, where the Westminster clock was made, and in his shops in the Strand and Royal Exchange, and all his patent rights; and that I do *not* mean the owner of the shop of the same name in Cockspur Street, who, I believe, is now a lady.

have become in many parts unsatisfactory to the author, unless his own knowledge has stood still; and it is less trouble to write things afresh, than to patch them up with emendations, if much emendation is required. Of course a great deal of the book will still be the same in substance; but a considerable quantity of new matter will be added. At the same time, I shall compress, or shorten, or omit various things which have become obsolete or useless since the first publication, except where they still have some interest as steps in the progress of invention, or where it is benevolent to warn people against wasting their time in inventing them again. I hope the improvement in the printing of this edition compared with the first will be observed, to the credit of the publisher. A few of the old woodcuts are used, but the great majority are new, and much better than in any of the previous editions.

I mention especially as new matter to be added, the description of some clock escapements which have come into use since the first edition; and also the complete history and description of the great clock of the Houses of Parliament, and its bells, up to the present time. In 1850, when I published the first account of the proceedings, the clock itself was not begun; and in 1857, when the last edition of this book was written, the clock was still in Mr. Dent's factory, and only one of the bells cast. I am told that many people are curious to see a complete history of the strange circumstances by which the work has been now delayed for no less than 16 years since the negotiations began. It is not arrogating much to myself to say, that there is no other person living who has the means of writing a true

history of the business, if he wished; and I have certainly not yet seen much indication of any desire to do that on the part of any of the numerous authors whom the subject has called forth; nor was any to be expected, considering who have had to be disappointed and defeated, not once, but many times, in the course of getting that clock and those bells up into Sir C. Barry's tower.

I shall add a chapter on bells in general, as a subject intimately connected with clocks, and one on which I know by experience, when I had to take the responsibility of designing the Westminster bells, that there is nothing of any practical value to be learnt from any book that I could find in this or any other language; and it is clear that there is a good deal more to be learnt yet, especially as regards the casting of large bells. I do not believe that a really good bell of five tons weight has been cast within the last 200 years.

In this edition, as in the former ones, I shall notice every new invention in horology which seems likely to be of any real value. I am only sorry that there are not more of them; but unfortunately the clockmaking trade is perhaps the most stationary of all the mechanical and scientific trades. In large towns, where there are men of noted skill in other branches of business of similar character, there are now actually fewer who have the reputation of being clever watch and clockmakers than I remember twenty years ago;* and

* I see that substantially the same remark was made in a pamphlet published by Mr. C. Frodsham, himself a chronometer maker, in 1849, and it seems to me to get more true every year.

the resistance to improvements, either in construction or in the modes of carrying on the business, is almost enough to baffle the efforts of the few masters who are anxious to effect them. As for the art of large-clock-making, we were scandalously behind the French in it a few years ago, until the late Mr. Dent set up a factory of his own, and began a revolution in the manufacture of such clocks in consequence of a combination against him, and reduced their price as much as he improved the quality; which, I have good reason for believing, is the true reason of the animosity which has long raged against him, and every body who supports or assists him or his successor. I do not know that a severer satire could have been written upon the state of that branch of the art, than was published by the London Company of Clock-makers themselves in 1852, in a memorial against the employment of Mr. Dent to make the Westminster clock, wherein they declared that the Hôtel de Ville clock at Paris, made in 1781, was still the best public clock in the world; which proved at any rate that the memorialists were not only innocent but ignorant of any improvements made in the last 70 years, and were determined to prevent anybody else from introducing them if they could. As nine out of ten of the turret clocks supplied by the so-called clock and watch-makers both of London and the country, are made for them on commission by a few manufacturers in the east of London, no doubt it is much pleasanter for them all to go on in the old way, than to have these alterations in construction and price forced down their throats by two or three enterprising men in London

and the north, who have some regard for science as well as money.

I know by experience that some persons will be disappointed because they do not find this Rudimentary Treatise almost as easy reading as railway literature. The only rudimentary treatise I am acquainted with, which does not require some previous knowledge, is that one which consists of the alphabet in large letters; and even that is not always found an easy and pleasant study, and is not to be mastered without more attention than is usually bestowed on a novel or a newspaper. I do not believe that the real rudiments of horological knowledge can be taught much more simply than they are here. They may be slurred over and pretended to be taught when they are not; or they may be assumed to be known, and so a book may be made to look easy by being exactly the opposite of rudimentary. For instance, I might put down certain conclusions respecting pendulums and escapements, and leave out all the calculations by which they are obtained, and so free these pages from the horrifying appearance of algebraical formulæ. But to call such a book a rudimentary treatise would be an imposture. At the same time, those who are not in a condition to follow the mathematical proofs, will find plenty to read without them; or they may, at any rate, accept the conclusions as readily as if the proofs had been omitted for the sake of making the book look easy; and after all, it is only a small portion of the subject which is afflicted with any mathematics.

Having thus explained how far this is a new book,

and what you may expect to find in it, we may as well begin business by considering what that thing is which clocks and watches are intended to measure. You need not be afraid that I mean to embark on a metaphysical disquisition on the nature of Time: I only want to explain that the things called days, hours, minutes, and seconds, are of several different lengths, and are reckoned from different epochs, with reference to the sun, the stars, and the purposes of common life; and that that which is the most commonly used of all is a purely arbitrary and conventional kind of time, agreeing with no real motion of any one of the heavenly bodies, or of the earth, or anything in nature.

SIDEREAL, SOLAR, AND MEAN TIME.

A sidereal day is simply the time of one absolute revolution of the earth, without reference to the sun or any other body in the universe; but the only practicable way of measuring it is by observing two successive transits of the same fixed star over the meridian of the place, since the fixed stars are at what may be called an infinite distance; and the only accurate way of doing that is by a telescope mounted across an east and west horizontal axis so that it can only move in the meridian or north and south plane. Such a telescope is called a 'transit instrument.' This absolute revolution of the earth is the only motion or period which is both perfectly invariable and directly observable in the whole solar system; and therefore, little as we hear in general of sidereal time, and widely as it differs from ordinary clock time, yet in fact all the clock time in

the world is kept in order by the sidereal observations made by the transit instruments of observatories and by calculations made therefrom.

But what is 24 or 0 o'clock at any given place by sidereal time? It is when a certain imaginary point in the heavens called ♈ (the first point of Aries), the intersection of the equator and the ecliptic, passes the meridian of that place. And it must be remembered that this ♈ has a very slow motion backwards called *precession*, amounting to 50″ of space every year, which is equivalent to $3\frac{1}{3}$ seconds of time; so that, after all, the sidereal day of astronomers is not quite identical with the period of two successive transits of a star, but is nearly the hundredth part of a second less; and in 26,000 years the sidereal time of astronomers, measured by this invisible point and their clocks, will have counted one full day more than if it had been reckoned by the visible star-clock of the heavens. As ♈ is not a thing observable by telescopes, the way to find 24 o'clock sidereal is to observe the time of transit of some star whose distance from ♈ in sidereal time, or in *right ascension*, is given in the Nautical or some other almanac for the year, and then you know whether your clock is right, or how much it is wrong.

A solar day is the interval between two successive transits of the middle of the sun over the meridian: and before that can happen the earth must make rather more than one absolute revolution, because it is moving on in its orbit round the sun at the same time and in the same direction as it turns itself. Consequently there is one more sidereal day in a year than there are

solar days, and the average solar day is 3 sidereal minutes and 56·5554 seconds longer than the sidereal day, or in the ratio of 1·002738 to 1. Solar time is no longer shown by anything but sun-dials, and they are almost obsolete and useless, except for a mere solar noon-mark, which affords a convenient and easy way of keeping clocks near enough to the time for all ordinary purposes, as will be explained presently. It was the fashion in France, so late as 1826, to make the public clocks show solar time, either by altering them nearly every day to suit the sun-dial, or by some complicated machinery; but that is now universally abandoned.

Since the ecliptic or the earth's orbit round the sun is oblique to the equator, solar days could not be equal, even if the orbit were a circle and the distance moved in it by the earth every day were the same; but it is an ellipse, with one end nearer to the sun than the other, and the earth moves faster when it is near the sun than when it is far off; and these two causes together (the former more than the latter) make the solar days vary in length considerably; so much, that they are a minute longer in December, and half a minute longer in June than in September or April; and if a common clock which goes perfectly right is set by the sun-dial in November, it will be half an hour before the sun-dial by the 10th of February. Hence it is that the afternoons appear to get dark too soon in October and November, and are so much lighter at an equal time after Christmas, and the mornings the contrary.

Mean Time. Although the length of the solar day

is thus variable, that of the year is invariable,* though it is no integral number of days. Consequently there is an average length of solar day which is just as constant from year to year as the sidereal day itself; and this conventional average day is the one which has long been adopted for all civil and many astronomical purposes, and it constitutes what is called *mean time*. The difference between it and solar time is called the *Equation of time*, which is sometimes as much as 14 m. one way and 16 m. the other. The following table, in the convenient form in which Mr. Dent annually publishes it, shows what time the clock ought to indicate at solar noon by a meridian instrument; remembering that this time has to be further corrected for the longitude to show what the Greenwich mean time is at the moment of solar noon at the place where you are.

The equation is not quite the same every year, because it moves on about a quarter of a day until leap year comes and puts it back again. But this table will be very nearly right for 1861-65, and every first year after a leap-year for a long time to come. And for the second year after leap-year it will be right enough if you subtract ¼ of the difference between any given day and the next, in this table, when the figures are increasing: *e.g.* on 1 January, 1861, the clock is before the sun 3m. 58 sec.; and on 2 January,

* This is not strictly true, as we are not speaking of the sidereal year, which is of the invariable length, 365 d. 6 h. 9 m. 9·6 s. (mean time), but of the *tropical* year, or the time of annual passage of the earth or sun from ♈ to ♈ again, which is now 365 d. 5 h. 48 m. 49·7 s., or 365·24224 days, but was 4·21 seconds longer in the time of the first great known astronomer, Hipparchus, 2000 years ago. See *Herschel's Astronomy*.

4m. 26 sec.; the difference between which is 28 sec.; and therefore the time of solar noon on 1 January, 1862, will be 3 m. 51 sec.; and for 1863 it will be 3 m. 44 sec. But when the clock time in the table is decreasing, you must *add* ¼ of the difference: *e.g.* on 1 September, it is 11·59·50, and on the 2nd, 11·59·31; adding a quarter of the difference or nearly 5 sec. gives the clock time for 1 September in the following year (the 2nd after leap year) right within 2 sec., which is quite as near as you can observe with any meridian dial or instrument short of a transit telescope. For the third year after leap-year you must of course add or subtract ½ instead of ¼ of these differences. Leap-year itself must be treated in the opposite way, adding instead of subtracting a quarter of the daily difference and *vice versâ,* as far back as 1 March, and then 29 February must be treated as if it were 28 February, and so on back to the beginning of the year.

In setting a mean time clock by sidereal observations you have nothing to do with the equation of time, which only relates to the sun. Some common almanacs, besides the Nautical, give the mean time at which certain stars and planets pass the meridian of Greenwich, and then the operation of setting the clock is simple and obvious enough. But it should be observed that astronomers' mean time has no A.M. and P.M., but is reckoned up to 24 hours from the noon after the midnight at which the civil day is considered to begin. Thus 11 A.M. 1 January 1860, of common life was 23h. 31 December 1859, with astronomers. Without some of the data which are only to be found in such

TABLE OF THE

FOR THE FIRST

Showing Greenwich clock time when the Sun is on the

Day of Month	January. H.	M.	S.	February. H.	M.	S.	March. H.	M.	S.	April. H.	M.	S.	May. H.	M.	S.	June. H.	M.	S.
1	0	3	58	0	13	55	0	12	33	0	3	55	11	56	57	11	57	31
2		4	26		14	3		12	21		3	37		56	50		57	40
3		4	54		14	9		12	8		3	19		56	43		57	50
4		5	21		14	15		11	55		3	1		56	37		58	0
5		5	48		14	20		11	41		2	43		56	31		58	10
6		6	15		14	24		11	27		2	25		56	26		58	20
7		6	41		14	27		11	12		2	8		56	21		58	31
8		7	6		14	29		10	57		1	51		56	17		58	42
9		7	31		14	30		10	42		1	34		56	14		58	53
10		7	55		14	31		10	26		1	17		56	11		59	5
11		8	19		14	31		10	10		1	1		56	9		59	17
12		8	42		14	30		9	54		0	45		56	7		59	29
13		9	5		14	29		9	37		0	29		56	6		59	41
14		9	27		14	27		9	20		0	14		56	6		59	54
15		9	48		14	24		9	3	11	59	59		56	6	0	0	7
16		10	8		14	20		8	46		59	44		56	7		0	19
17		10	28		14	16		8	28		59	30		56	8		0	32
18		10	48		14	11		8	11		59	16		56	10		0	45
19		11	6		14	5		7	53		59	2		56	12		0	58
20		11	24		13	58		7	35		58	49		56	15		1	11
21		11	41		13	51		7	17		58	37		56	19		1	25
22		11	57		13	43		6	58		58	25		56	23		1	38
23		12	13		13	35		6	40		58	13		56	28		1	51
24		12	27		13	26		6	22		58	2		56	33		2	4
25		12	41		13	17		6	3		57	51		56	38		2	17
26		12	54		13	7		5	45		57	41		56	44		2	29
27		13	7		12	56		5	26		57	31		56	51		2	42
28		13	18		12	45		5	8		57	22		56	58		2	54
29		13	29					4	49		57	13		57	6		3	6
30		13	38					4	31		57	5		57	14		3	18
31		13	47					4	13					57	22			

EQUATION OF TIME,

YEAR AFTER LEAP YEAR.

meridian, after correcting for the longitude of the place.

Day of Month	July.			August.			September.			October.			November.			December.		
	H.	M.	S.	H.	M.	S.	H.	M.	S.	H.	M.	S.	H.	M.	S.	H.	M.	S.
1	0	3	30	0	6	2	11	59	50	11	49	38	11	43	43	11	49	19
2		3	41		5	58		59	31		49	19		43	42		49	42
3		3	52		5	53		59	11		49	0		43	42		50	8
4		4	3		5	48		58	52		48	42		[illegible]	43		50	30
5		4	13		5	43		58	32		48	24		43	45		50	[illegible]
6		4	24		5	36		58	12		48	6		43	47		51	28
7		4	33		5	29		57	52		47	49		43	50		51	46
8		4	43		5	22		57	31		47	32		43	55		52	12
9		4	52		5	14		57	11		47	16		44	0		52	39
10		5	0		5	5		56	50		47	0		44	6		53	6
11		5	9		4	56		56	29		46	45		44	12		53	34
12		5	16		4	46		56	9		46	30		44	20		54	2
13		5	24		4	36		55	48		46	16		44	28		54	31
14		5	30		4	[illegible]		55	27		46	2		44	38		55	0
15		5	37		4	14		55	6		45	49		44	48		55	29
16		5	43		4	2		54	44		45	36		44	59		55	58
17		5	48		3	49		54	23		45	24		45	11		56	28
18		5	53		3	36		54	2		45	13		45	24		56	57
19		5	58		3	23		53	41		45	2		45	37		57	27
20		6	2		3	9		53	20		44	52		45	51		57	57
21		6	5		2	55		52	59		44	42		46	7		58	27
22		6	8		2	40		52	39		44	33		46	23		58	57
23		6	10		2	25		52	18		44	25		46	39		59	27
24		6	11		2	9		51	57		44	17		46	57		59	57
25		6	12		1	53		51	37		44	[illegible]		47	15	0	0	27
26		6	13		1	37		51	[illegible]		44	5		47	34		0	57
27		6	13		1	20		50	56		43	59		47	54		1	27
28		6	12		1	3		50	36		43	54		48	14		1	56
29		6	10		0	45		50	17		43	50		48	35		2	25
30		6	8		0	27		49	57		43	47		48	57		2	54
31		6	5		0	8					43	45					3	23

an almanac, it is of no use attempting to find the time from sidereal observations, and therefore it is not worth while to give any less simple modes of doing it from other data than those just mentioned.

But you may *regulate* the rate or going of a mean clock from sidereal observations without the aid of any tables or astronomical data, though you cannot *set* it to the actual time. The mean day is 3m. 56·5554s. sidereal longer than a sidereal day; and therefore sidereal hours, minutes, &c., may be turned into mean ones by multiplying them by ·99727, or by subtracting 9·83 seconds from every hour, and 1 second from every 6m. 6s. And as the 3m. 56·55s. sidereal = 3m. 55·7s. mean, the mean clock ought to show so much less at the second transit of a star, than the time it showed at the first transit.

This operation may also be performed with sufficient accuracy without a transit instrument. For if you make a small eye-hole in a thin plate, fixed looking south, and set up, or find anywhere due south of it a perfectly vertical straight edge, the occultation or emergence of any given star against that straight edge will be seen through the eye-hole at exactly every 24 sidereal hours, or at every 23h. 56m. 4·3s. of mean time. And it is not necessary for merely regulating a clock, that the hole and the edge should be very exactly in the meridian, if you only use it for observing stars not far from the equator. But if you aim at using it for setting as well as regulating your clocks, with the help of astronomical tables, then you must take care to have the hole and the edge exactly in the meridian. Probably the best way of doing this, is to fix the plate

by carrying the time by two or three chronometers of known rate, from the nearest observatory, using the almanac time of the southing of one or more stars.

In all operations for setting clocks from any kind of celestial observations, you must remember the difference between your own longitude and that which is the standard of the country, which is here the Royal Observatory at Greenwich; though it is only since the publication of the first edition of this book that some places in the west of England have condescended to adopt that universal time, and others have compromised the matter by putting two minute hands to their clocks, one for local and the other for Greenwich time. Christ Church, Oxford, keeps both times by different clocks, the cathedral still adhering to local time, while '*Tom*' (whose clock seems not much better than himself) professes Greenwich time, and so do the other college and town clocks now. The meridian you use must be the true one of the place, and not a false one adapted to Greenwich beforehand (unless the longitude is very small) and the correction must be made at the rate of 4m. to a degree of longitude. For instance, in using the above equation table at Doncaster, 4m. 12s. must be added to the time throughout; for on the four days in the year when the equation is nothing, the Greenwich clocks will show 0h. 4m. 12s. when the sun has reached the Doncaster meridian. Here is a table of some forty towns, showing how much the clock ought to be before or behind solar time if it is to agree with Greenwich, or what is popularly called railway time; *i. e.*, the time which railway trains profess to keep, but never will regularly,

until the companies are made to forfeit their fares whenever they do not keep the time they choose to publish.

GREENWICH TIME BEFORE LOCAL.	M.	S.		M.	S.
Westminster Palace	0	30	Carlisle	11	38
Peterborough	1	0	Liverpool	11	53
Hull	1	8	Edinburgh	12	43
Lincoln	2	4	Exeter	14	18
Doncaster	4	12	Plymouth	16	30
York	4	24	Glasgow	17	0
Portsmouth	4	24	Holyhead	18	36
Leicester	4	33	Cardigan	18	40
Oxford	5	1	Falmouth	20	12
Southampton	5	36	Dublin	25	22
Derby	5	52			
Leeds	6	4	LOCAL TIME BEFORE GREENWICH.		
Newcastle	6	24			
Lichfield	7	18			
Birmingham	7	33	Grimsby	0	0
Berwick	8	0	Louth	0	0
Aberdeen	8	23	Boston	0	0
Worcester	8	41	Cambridge	0	23
Manchester	9	0	Colchester	3	32
Bath	9	26	Ipswich	4	38
Bristol	10	12	Norwich	4	48
Shrewsbury	10	56	Dover	5	16
Chester	11	32	Paris	9	21

INSTRUMENTS FOR MEASURING TIME.

At the head of these of course stand the oldest of them all, sun-dials. But it would be a waste of time to say much about them, except in the forms in which they may be made subservient to the more useful and

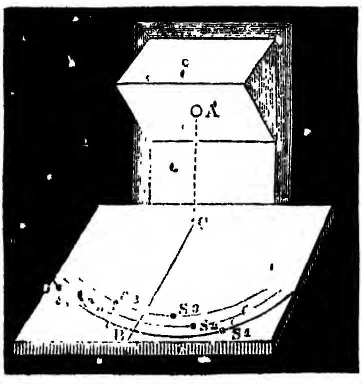
accurate machines by which they have been superseded. The principal feature of all sun-dials which have to indicate other hours besides noon is a *gnomon*, with a straight edge, or pair of edges, parallel to the earth's axis, and therefore inclined to the horizon at an angle equal to the latitude of the place, with a plate for the gnomon to throw a shadow on. Thus an Indian sun-dial has its gnomon nearly level, and a polar one would be quite upright. If the plate of the dial is a cylinder of which the edge of the gnomon is the axis, all the hour divisions will be equal, but not otherwise. The divisions before and after noon are equal when the plate is either horizontal both ways, or inclined only to the south, or vertical on a south wall. Sometimes they are set in other fanciful positions; in whatever position the plate is, the same hour marks will do for all times of the year, provided only the gnomon is parallel to the earth's axis. But all that belongs to the art of *dialling*, which may be found in any of the encyclopædias, and is of no use to us, especially as sun-dial observations cannot be relied on with any accuracy except when the sun is near the meridian.

Meridian dial. A solar meridian mark or sun-dial for noon only is intelligible and usable by many persons who cannot or will not undertake sidereal observations, and is so easily made that everybody ought to have one who cares about having accurate time, and has not the means of getting it from some other source. The simplest of all ways of fixing such a mark is to set up a plate facing the south with a narrow vertical slit in it, reaching down to the bottom, upon a horizontal slab of smooth stone, and mark the line of brightness on the

stone at the time of solar noon by a chronometer or good watch carrying the time from some reliable source. Mr. Dent makes these gnomons as zinc plates fixed on a small cast-iron standard in a convenient form for fixing, and they cost only a few shillings. The line once drawn is right for ever, provided the slab and the gnomon are fixed firm and right at first.

It may be worth while to explain how such a thing may be fixed independently of a chronometer. This picture represents only another form of the same instrument, in principle just the same, but in practice not so convenient, except where you have room for a very long plate, on account of the length of the shadow in winter. Here A may be considered either as a small hole in a thin copper plate AD (such as is fixed in the roof of the clock-room at the Doncaster railway-station, about 9 inches above the slab) or as the top of the slit in the upright gnomon, which in that case is represented by the vertical line AC down to the slab, which must be made exactly level for this purpose. At a little before 11 on a fine day in the summer half of the year, mark with a pencil where the bright spot or end of the bright line falls upon the slab, say at S_1 and draw the arc of a circle

Fig. 1.



with radius CS_1. Mark again two other spots S_2 S_3 before noon, and draw the circles through them in the same way. Then watch for the times after noon when the bright spot falls upon the several circles again, and mark those places s_1, s_2, s_3. Bisect each of the three distances S_1s_1, S_2s_2, S_3s_3, and if you can draw a straight line CB from C through all the bisections, the observations have probably been correct, and you may consider CB the meridian line. But before you cut it into the stone, you had better repeat the process on several days, and also try it by a chronometer if you can. I fixed the first that was made of these upright gnomons in this way in a garden 21 years ago, without any chronometer, and it afterwards had the honour of being examined by Professor Challis, who is the head of the Cambridge observatory, and was found right within 3 or 4 seconds.

It is convenient to have an equation table cut on the stone, to be always at hand. It is enough to put in the days where the change in the equation amounts to a minute, which are only about 80, and the 4 days of maximum, as you can easily interpolate the rest when you want them. The table engraved had better be for the first year after leap year, and you can correct it for any other year by the rule given at p. 10. It will also save trouble and diminish the chance of mistakes, if you incorporate the local difference from Greenwich time with it. Thus the table to be cut on a sun-dial at Doncaster would show *Clock time of solar noon on* 1 *January* 1861, as 0h. 8m. 10s. If you prefer the other form, of 'Clock before or after sun,' then the table must show *Clock after sun on* 1 *November*, 12m. 4s., instead

of 16m. 16s. as it is at Greenwich. Of course the further west you go, the fewer days of clock after sun there will be in your table; *clock* meaning Greenwich time, remember.

The Dipleidoscope is another meridian instrument, which was invented by the late Mr. J. M. Bloxam, a barrister in considerable practice, whose name I shall have to mention again in connection with some clock inventions. He took out a patent for it and assigned it to Mr. Dent, by whom only they are made. Its name, compounded of διπλόος double, εἶδος an image, and σκοπέω to see, indicates the principle of it; because in all positions but one you see a double image of the sun reflected in it; and if it is so fixed that the single image—*i.e.*, the coincidence of the two—occurs at solar noon, it evidently becomes a meridian instrument. It has the advantage also of reflecting the sun when it is just too cloudy for a bright spot to be distinct, and in fact you can only look at it through smoked or coloured glass when the sun is bright.

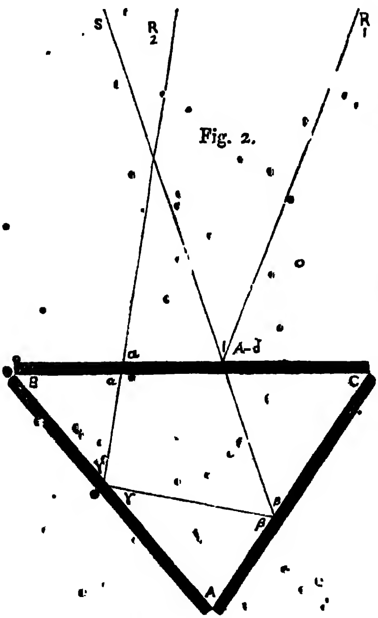


Fig. 2.

The instrument consists of three small plates of glass put together at their edges in a brass box about 2 inches wide and high, so as to form a hollow prism of any convenient angle, no precision being necessary in this. A B C in this figure is the section of it at right angles to the axis of the prism. The front glass B C is plain; the other two are blackened behind to form reflectors. But though the front glass is transparent, it also reflects, because there are dark ones behind it. S I and I R[1] are sections of the planes of incidence and reflection of the sun's rays from the glass B C. But part of the rays passes through that glass, and is reflected by glass A C to A B, and again reflected there and sent through B C to R_2. Now let the angle of incidence, and therefore of first reflection, at I be called $A-\delta$ (A being the angle of the two reflecting glasses), and let the other angles be designated as in the figure. It requires no mathematics beyond the knowledge that the three angles of every triangle = 180°, commonly called π, to see that the angle $\beta = \pi - (C + A - \delta)$ in the small triangle near C; and in the one near A, $\gamma = \pi - (A+\beta) = C - \delta$; and in the triangle near B, $\alpha = \pi - (B+\gamma) = \pi - (B+C - \delta) = A+\delta$. That is to say, the angle α, made by the plane of emergence of the twice reflected rays with the front glass, differs from that of the once reflected by $2\,\delta$. Therefore if the prism is so placed as to make $\delta = 0$, which it will be if the angle of incidence = A, the twice reflected rays will come out parallel to the once reflected, and the two images of the sun will coincide. In fixing the instrument however, we have nothing to do with the angles; but simply to adjust it by trial with a chronometer (for

it cannot be done without), so that the images do coincide at the time of solar noon.

They were at first made so as to be fixtures on the stone where they were set, and so they were always exposed to the weather, and besides, if cemented in wrongly, they were wrong for ever. To avoid both these evils, I suggested the making of a brass plate to be fixed on the stone, with a raised slip adjustable by screws, against which the instrument is to be laid closely when used, but at other times it may be kept in the house. Mr. Dent also makes some of them to turn on an axis parallel to the earth's axis, and then they can be presented to the sun at other hours besides noon, but only for the given latitude like a sun-dial. Some are made adjustable for latitude also. They are moreover made for star observations with the reflectors silvered instead of blackened, on account of the greater feebleness of the light. Mr. Dent publishes a table to be used with them, which shows the time of first and last contact of the two images of the sun for every day in the year, as that is observable perhaps more accurately than the time of coincidence; at any rate it gives three chances of observation instead of one.

WATER AND SAND CLOCKS.

The earliest time-keeping *machine* is the clepsydra or water-clock of the Greeks and Romans, which was no doubt made in various ways. Vitruvius mentions one made as a water-wheel, which would probably be very irregular. The simplest in construction is a graduated cylindrical vessel with a hole in the bottom, and this

appears to have been the most commonly used: but they must surely have discovered that the water in that case by no means runs out with uniform velocity, though they did not know, and some of the modern writers on antiquities apparently do not either, that the velocity varies as the square root of the height of the water above the hole. But if a trough is kept full by a stream, and a hole made anywhere in it, the water will then run uniformly into, and rise uniformly in another cylindrical vessel, in which its height may be marked on the sides, if it is of glass, or else by a floating index, and that will make a very fair clock. I do not however find any notice of such a one in books of Greek and Roman antiquities. Various other forms of clepsydra are described in them, which it is not worth while to copy here.

The case is different with sand. If a column of dry sand ever so high stands over a small hole, the sand will run out no faster than if it is a very moderate height, for the same reason that a pile or cone of sand on a given base will stand up to a certain height and angle only, which depends on the amount of friction between the particles. The angles of the waist of an hour-glass ought to agree with that natural angle of the sand in order that it may run out uniformly to the end—if that is of any consequence, which it hardly is for the boiling of eggs, or even for the old use of limiting the length of sermons; which object might sometimes be advantageously accomplished now by a descending sounding-board, or as sounding-boards are gone out of fashion, by a pulpit-bottom or 'drop' let down by clock-work at the proper time.

The burning of graduated candles was another mode of marking time, and if the candles were of wax, as they probably were, and sheltered from wind, and the wicks uniform throughout, the measure would be accurate enough for any purpose for which it was likely to be used. The consumption of oil in a lamp might also be marked and used in the same way. But it would be a waste of time to describe any more forms of these now obsolete instruments, and we may as well proceed at once to what we now understand by the term clock-work.

CLOCKS.

The invention of clocks driven by a weight has been sometimes attributed to Pacificus, archdeacon of Verona, in the ninth century; though many writers have come to the conclusion—I do not know on what grounds, that his was only some new kind of water-clock. And as it seems to be admitted that Gerbert, afterwards Pope Silvester II., made a clock at Magdeburg in 996, when he was an Archbishop, I do not see why Archdeacon Pacificus should be considered incapable of having made perhaps an inferior one in the century before. We have however no evidence of clocks of anything like the construction of the last 500 years until the thirteenth century. Lord Chief Justice Coke tells the story of the first Westminster clock being put up out of a fine imposed upon a corrupt predecessor of his own in 1298. The Exeter cathedral clock, of which the striking part is still in action (or was very lately), is said in Britton's history of the cathedral, to have been in existence in 1317; and one by Robert

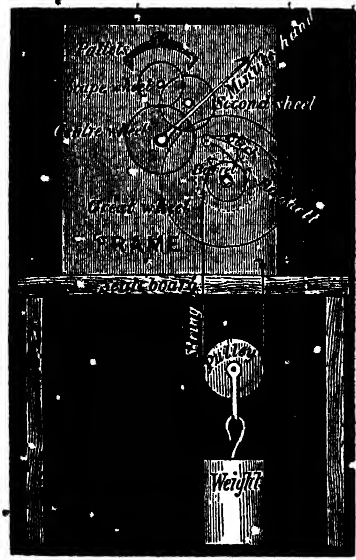
Wallingford, Abbot of St. Albans in 1326, is spoken of as containing some new invention, but I do not know what. The clocks of Wells and Canterbury, and I have no doubt, of Peterborough, were of about the same date. The striking parts of Peterborough and Exeter are still wound up by spokes in a long wooden barrel, and are of a much more primitive construction than that clock made by Henry de Vick, for Charles V. of France in 1370, of which the description has been several times printed. Captain Smyth also published a description in 1841 of one at Dover Castle with the date 1348 upon it. It had a pendulum, and so have the Exeter and Peterborough clocks (though their going parts are not now used), which I suppose must have been added long afterwards, unless the date commonly assigned to that invention is wrong by three centuries. It is not until quite modern times that church clocks had minute hands besides the hour ones, but in other respects there is surprisingly little difference in principle between the oldest of these machines and the turret clocks of most of the makers of the present day.

The going part of a clock is, and always has been, nothing but a train of some number of wheels and pinions, of which one turns in 12 hours, and another in 1 hour, if there is a minute hand. The first, or slowest, or 'great' wheel is turned by a weight hanging by a rope wound round a barrel on that wheel's axis, or *arbor*, as it is called in clock-making; and the last, or quickest wheel drives a fan-fly, or a fly-wheel, or a pair of vibrating arms called a 'balance,' or a pendulum, to regulate the velocity of the train. A spring

clock is merely a compound of a large watch and a common clock, and therefore we need not extend the definition to include that.

Perhaps the rudimentary reader does not know what a 'train of wheels and pinions' means, as it is not a phrase in much use except in clock-making. This picture will help to explain it. The wheel called *scape-wheel* is intended to turn in a minute, suppose; which depends on the pendulum, which we have nothing to do with yet. Its axis, or arbor' has a small wheel or *pinion* (say) of 7 teeth or *leaves* fixed upon it, and that is driven by the second wheel with 56 teeth, which therefore turns in 8 minutes, and that has a pinion of 8 on its arbor, which is driven by the *centre-wheel* of 60, which therefore will turn in an hour, and is adapted to carry the minute hand. The centre-wheel again may have a pinion of 8 on its arbor, and if that is driven by the great wheel with 96 teeth, of course that will turn in 12 hours, and might carry the hour hand, and used to do so in the old clocks without minute hands; but that

Fig. 3.



is generally now done otherwise, as I will explain presently. The barrel and not the wheel is fixed to the arbor of the great wheel, and has one end cut into teeth, like saw teeth, so as to form what is called a *ratchett*, whose teeth can pass under a spring or *click* fixed upon the great wheel, in one direction, but not in the other. The great wheel is not fixed upon the arbor, but rides loosely on it, and the end of the arbor is long and comes through the frame, and is made square, so that a key may fit it to wind the barrel in the direction in which it can move under the click without moving the wheel; and then, when you have done winding, the weight evidently pulls it the other way and moves the whole train.

You must understand that there is no virtue in the particular numbers of teeth in the wheels and leaves in the pinions which I have given: all that is requisite theoretically, is that the numbers of the teeth of all the wheels multiplied together, and divided by the numbers of the leaves of all the pinions multiplied together, should give the proper velocity-ratio between the slowest wheel and the quickest. Thus, if the scape-wheel has to turn 60 times as fast as the centre wheel, and there is one between them which may turn in any time, the product of the teeth divided by that of the leaves must = 60, and subject to that, you may distribute the numbers as you please—theoretically; but practically other considerations come in, such as that the slower wheels must be larger than the quicker ones—that if the leaves of the pinions are very few they do not drive easily, and if they are many, the teeth must be many and small, and more expensive to cut,

and so forth; and the result is that, in the common long house clocks, the numbers are usually what I gave just now, but in astronomical clocks, or *regulators*, they are higher, sometimes twice as much; in turret clocks they vary more according to circumstances, as will be seen hereafter.

The simplest of all the methods of regulating the velocity of the train, and one which certainly existed before De Vick's time, is the fan-fly, or a pair of arms with vanes which are resisted by the air. I think it by no means improbable, though it is never likely to be ascertained now, that some of those earlier clocks, perhaps even Pacificus's in the 9th century, were trains of wheels with a fan-fly to regulate their velocity, instead of a balance, which De Vick used in his going part, though he had a fly in the striking part, as the earlier English clocks have, and exactly as it is used to this day. So long as the force and friction of the train are uniform, the velocity of the fly will be uniform, as the variation of density of the air is too small to affect it materially; and it should be observed, that a long fly with a rather slow motion is less affected by variations of force than a short and quick one; but as far more accurate methods are now used, it is unnecessary to go further into this.

A fly-wheel, which is either a wheel with a heavy rim or a pair of weighted arms at right angles to the axis which carries them, is another method; but not so good, because it is much more affected by a change of force, which in clock-work nearly always means a change of friction in the train. It acts simply by its moment of inertia, which is constant, and therefore the

velocity cannot be constant if the force varies. In fact there is theoretically no limit to the velocity of a fly-wheel driven by a weight, so long as the weight can go on falling, though practically a terminal velocity is soon reached, when the friction and the increasing resistance of the air balance the force; but of course this balance is disturbed, and the velocity changes, as soon as the force varies.

Conical Pendulum. A pair of weighted arms attached to a revolving vertical axis by horizontal hinges, so that they can fly further out as they go, will regulate the velocity more completely than a fly-wheel or arms rigidly fixed, but still not completely enough to keep it uniform if the force varies much. They are like the 'governor' of a steam-engine in appearance, but no further; for the governor-arms work a lever which opens more or less of the throttle-valve of the steam-pipe, according as the engine is going too slow or too fast. A single ball or pair of balls hung in this way and driven by a clock-train form what is called a *conical pendulum*, because each arm describes a cone, and the time of its revolution may easily be determined as follows, except so far as it is affected by friction and resistance of air :—

Let l be the length of each arm and ϕ the angle at which it happens to be inclined to the vertical axis, which of course depends on the rate of revolution or angular velocity, which is usually called ω; then the centrifugal force of each ball $= \omega^2 \, l \sin\phi$; and as that is the force which keeps the balls away from the vertical, it must balance the force which draws them to

it, which is $g \tan\phi$ (g being the usual symbol for the force of gravity, or twice the number of feet which a body falls in the first second of time, which in this latitude is 32·2); therefore ω, or the angular space moved over by the arms in one second $= \sqrt{\frac{g}{l \cos\phi}}$ and the time of a complete revolution through 360° or 2π, is $\frac{2\pi}{\omega} = 2\pi\sqrt{\frac{l\cos\phi}{g}}$. If you wish to know what that means in figures, you must express l in feet, as g is, and write the numerical value 3·14159 for π, and take the numerical value of $\cos\phi$ from a table of sines and cosines, and the result, after extracting the square root and dividing, is the number of seconds in which the revolution is performed. We shall see hereafter that it is just so much less than the time of a common vibrating pendulum of the same length as $\sqrt{\cos\phi}$ is less than 1. And as the cosine varies least when an angle is small, a clock of this kind will go better when the length of the arms and the weight of the balls are such that they make only a small angle with the axis when the clock weight is driving them. But again it must be remembered that these results are very much modified in actual working by the resistance of the air, which acts more strongly on the balls as they fly farther out, and thereby tends to regulate the velocity, as it does with a fan-fly.

A clock of this kind is often used to turn the reflectors or coloured lenses of revolving light-houses, and also for the still more accurate purpose of driving large equatorial telescopes, to keep them pointed to a star notwithstanding the revolution of the earth. For

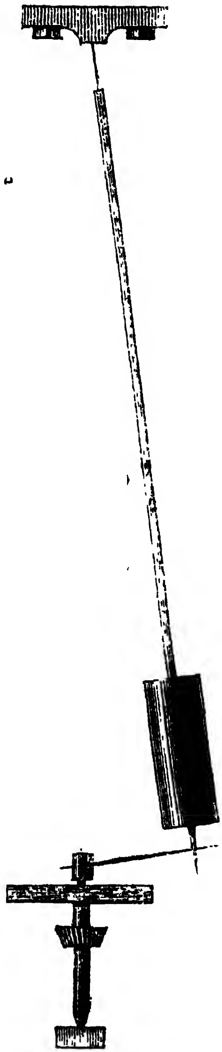
the same purpose some kinds of water-clocks are also used, not at all on the principle of the ancient *clepsydræ*, but on that of Barker's mill, as it is called; in which two hollow horizontal arms are fixed on a hollow vertical axis into which water runs at the top; each arm has a small hole near its end, on opposite sides, from which the water jets horizontally, and makes the arms revolve in the opposite direction. The reason why contrivances of this kind are required for telescope-driving is that a clock train regulated by a pendulum and escapement moves by jerks, which the earth does not.

As I understand Mr. Airy's description of this machinery for driving the new equatorial at Greenwich, the governor attached to the water-clock does work a throttle valve, like that in a steam engine, for regulating the flow of water into the Barker's mill. He also mentions a 'spade', attached to the conical pendulum, I suppose, by a lever on the opposite side of the axis, which dips into a trough of water when the pendulum swings out too far or goes too fast. I have no means of judging from experience whether these contrivances are better or worse than that of Messrs. Wagner of Paris, described under fig. 37 hereafter. It is certainly a neater one than any of these; but as it was seen at work here in the 1851 Exhibition, I presume it has not been rejected for the water and conical pendulum apparatus without full consideration.

The best way of driving a conical pendulum in a clock seems to be that shown in the next page. The pendulum may be hung by a thin piece of wire, as it has no disposition to twist; for it would require a

greater force to make it twist on its own axis besides revolving. Another way which has been adopted at Greenwich is to hang it by a kind of universal joint made with springs instead of pivots, probably because a wire strong enough for a 15 lbs. pendulum would be too stiff as a spring. The motion is kept up by a light arm sticking out from a vertical axis driven by the clock-train and turning in 2 sec. (if it is a common one-second pendulum), and acting on a tail or spike from the bottom of the pendulum. There is generally some friction apparatus besides, which can be made to act more or less strongly on some wheel in the train, either by the observer as he finds the clock driving too fast or too slow, or by automatic apparatus as in Mr. Airy's clock at Greenwich for driving the chronographic cylinder covered with paper for recording observations.

Fig. 4.



It is perhaps worth mentioning that any point in a wheel revolving uniformly has always the same velocity in a horizontal

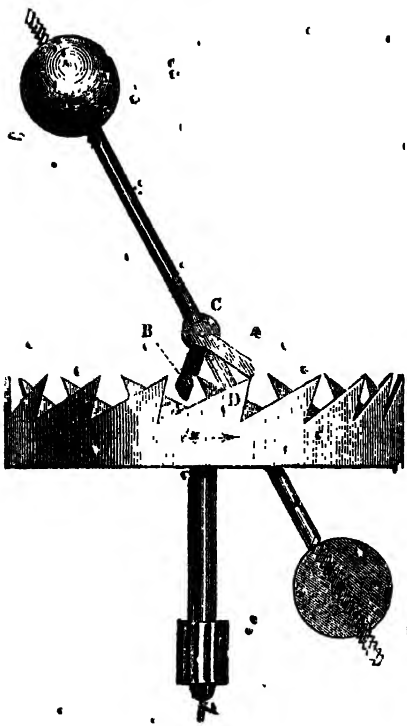
direction as some point in a pendulum which makes a double vibration in the same time as the wheel revolves; and therefore, theoretically, a constant motion of a clock-train might be got by connecting some point in a 1 sec.-pendulum with a pin in a small disc revolving in 2 seconds, by a rod so long as to be practically horizontal. But it would probably be impracticable to keep the force constant enough to give just proper impulse to the pendulum; and if too much was given, there would be a jerk at the end of every beat, and if too little, the pendulum and the clock would stop.

BALANCE-WHEEL ESCAPEMENTS.

Before we go into the theory of pendulums we should notice the one other mode of regulating the motion of a clock-train, which existed long before pendulums were applied. The earliest *escapement* of which there is any known description is that which De Vick's clock had, and which is called the crown-wheel escapement. The object of that, as of all the later escapements, was to let a tooth of the quickest wheel in the train escape past some stops called *pallets* at every vibration of the balance, and that wheel is thence called the scape-wheel, and a crown-wheel from its shape. The pallets A, B, in fig. 5, are pieces of steel fixed to the axis or arbor of the balance C in planes at right angles to each other, one of them set so as to be pushed one way by the front teeth of the wheel, and the other the other way by the back teeth. As one tooth escapes past its pallet, the other pallet is in a position to receive and stop the opposite tooth. But as the balance has then

acquired a swing in the direction in which it has been pushed by the escaping tooth, it does not stop immediately, but swings a little farther and so drives the wheel back again a little, producing what is called the recoil. This is just the same as the old 'vertical' watch escapement, which remained in use until a few years ago, with this important exception, that the time of vibration of a watch balance is regulated by a thin spiral spring fixed to it and to the frame, whereas this had none, and so its regulating power over the train depended solely on its moment of inertia, and on its swinging farther for any increase of force, which by no means makes it isochronous.

Fig. 5.



The same thing is still to be found in bottle-jacks; the piece of meat to be roasted forms the balance, and the noise at each change of its motion is the 'ticking'

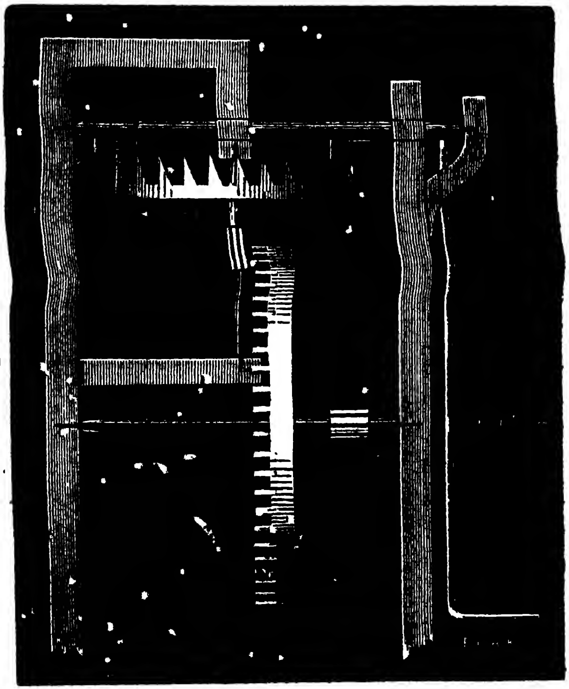
of the escapement. It is true the meat makes several turns for one tick, while De Vick's balance made only half a turn, but that is because there is a wheel on the pallet arbor in the jack, worked by a pinion on the meat arbor, as in the rack-lever watch escapement; but otherwise the bottle-jack escapement is precisely the same as in De Vick's clock, in which the axis of the balance was vertical, and not horizontal as in fig. 5.

PENDULUMS.

Pendulums, like many other things, may have been invented several times over in different ages, or even in the same. In an old edition of the *Encylopædia Britannica* it is said that 'the ancient astronomers of 'the east employed pendulums in measuring the times of their observations, patiently counting their vibrations 'during the phases of an eclipse, or the transit of the 'stars, and renewing them by a little push of the finger 'when they languished; and Gassendi, Riccioli, and 'others, in more recent times followed their example.' If so, it is plain that this knowledge had itself languished and died, before the making of what has long been called Galileo's discovery in the church at Florence, that a chandelier, and therefore any other pendulum, vibrated different arcs in the same time, provided they were none of them large ones. When we consider the vast number of pendulums of various kinds that there are swinging about the world, it certainly is difficult to imagine that nobody ever made that observation before the 16th century. The application of it to the regulating of clocks however is

a different thing, as that required invention as well as observation. To be sure, all that was needed was to omit one of the weights in De Vick's balance, and set it in a vertical instead of a horizontal plane, and it is strange enough that this slight but valuable alteration should have waited three centuries to be made. It would then assume this form, which is evidently the same as the other in all but the position of the parts and the omission of one arm and weight of the balance. The bent end of the arm (called the *fork*) is substi-

Fig. 6.



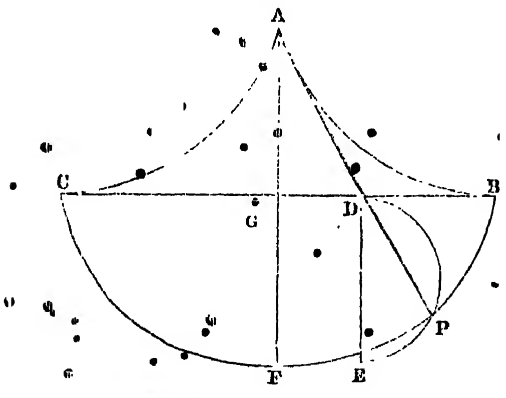
tuted for a weight in this drawing, because it was afterwards found better to hang the pendulum independently, and connect it with that arm, called the *crutch*, by means of the fork. But I have seen small clocks of the last century, and even some modern French ones, with the crutch itself made into a pendulum by merely putting a ball at the end of it.

There seems no doubt however, that the first person who investigated and established the mathematical theory and properties of the pendulum was Huygens, the Dutch philosopher, in the 17th century; but it seems equally certain that the first pendulum clock was made for St. Paul's Church in Covent Garden, by Harris, a London clock-maker, in 1621, though the credit of the invention was claimed also by Huygens himself, and by Galileo's son, and Avicenna, and the celebrated Dr. Hooke, the undoubted inventor of the balance spring of watches, and the discoverer of its theory.

The main point of Huygens's discovery seems at first sight a long way off any connection with what we now understand by a pendulum, viz., a weight or *bob* at the bottom of a long rod, which is hung by a string or a thin spring at the top, and the bob therefore swinging in a circular arc, or something very near it. For he proved that the curve in which a bob hung by a string of insensible weight must move in order to be isochronous in its vibrations, is *not* a circle, but a cycloid, or the curve traced out by a point in the rim of a circle rolling upon a straight line, *e. g.*, a nail in the tire of a carriage-wheel rolling on a smooth road, or P in the circle D E P rolling on B G C in fig. 7; and he

shewed how a certain other property of the cycloid might be made use of to enable a pendulum bob to describe a cycloidal instead of a circular arc. It is not worth while to fill these pages with demonstrations which may be found in any mathematical treatise on mechanics, especially as I must assume the reader to have some of the knowledge which is only to be got from such books, in order to understand the demonstrations if I gave them. Therefore we may as well begin at this point, that a body moving by gravity in a cycloid (with the curve downwards, as B P F C in fig. 7) does describe both large and small arcs in the

Fig. 7.



same time; the reason of which is that the force may be proved to be always in proportion to the distance along the curve from its lowest point, F.

But how is a pendulum bob, hung by a string or wire from a fixed point, to be persuaded to describe a cycloid? It so happens that if a cycloid B F C is cut

in two, and one half B F removed as a solid with a convex edge to A C (making A G=F G=D E), and the other half to A B, the end P of a string = A F, fixed at A, and moving between those 'cycloidal cheeks' will redescribe the old cycloid B F C. This is mathematically expressed by saying that the *involute* of a cycloid is another equal cycloid, and therefore also the *evolute* is; the evolute being the cheeks, and the involute the curve described from them: the proof of this belongs of course to geometry, not mechanics, and is of no consequence to us at present. Huygens therefore proposed to hang clock pendulums by a string or a thin spring between cycloidal cheeks; and that was for some time thought a very superior method of making clocks. I have no doubt there are some still in existence, as I have seen them myself.

But after a time it was found that clocks went rather worse with these cheeks than without them; and then it occurred to somebody that the cycloidal theory is only true for what is called in mathematics a simple pendulum, or one in which not only the bob, but the centre of the bob, is alone supposed to have any weight; and of course there is no such thing possible, for the rod must have some thickness, or it is not stiff enough to work, or to be driven by the clock, and if you make the bob very heavy, with the view of rendering the weight of the rod insignificant, then the bob itself must be large, and differs considerably in its mechanical effect from a single imaginary heavy point at its centre. And besides that, the spring or string cannot be made to act against the cheeks without friction and other disturbing causes; all which

things are said to have been proved to produce greater deviations from isochronism than a variation of several degrees in the arc. Indeed we shall see hereafter that the common clock escapements tend to produce an error of their own, which the deviation from cycloidal vibration (commonly called the *circular error*) is actually useful in counteracting.

Nevertheless, the cycloidal theory is valuable to this extent: it shows why a common pendulum is very nearly isochronous for different *small* arcs; for the string A P will evidently describe very nearly the same curve near the bottom F, whether the cheeks are there or not: in other words, a bob vibrating in a small circular arc is almost identical with one in a cycloidal arc described by a string of the same length. The actual time of a circular vibration cannot be calculated without the aid of the higher branches of the integral calculus, and even then it can only be exhibited in the form of a rather awkward series, which would be little better than useless, except for small arcs; and for them it is quite sufficient to take only the two first terms of it. The whole calculation may be found in Pratt's *Mechanics*, or in the 8th edition of the *Encyclopædia Britannica*, under article *Pendulum*. The first term is simply the expression for a cycloidal vibration, $t = \pi\sqrt{\frac{l}{g}}$, the letters of which I have already explained at p. 30, for the conical pendulum, whose time of vibration you now see is less than that of a plane pendulum of the same length in the proportion of $\sqrt{\text{cosine}}$ of the angle which the conical one makes with the vertical axis.

Circular error. The next term in the series (omitting all the later ones which are still smaller) constitutes the circular error K, or the excess of the time of vibration in a circular arc over that in the cycloidal one belonging to the same length of pendulum; and it is accurate enough for all practical purposes to say that $K = \pi \frac{a^2}{16}\sqrt{\frac{l}{g}}$; and therefore for a whole day, $K = 5400\, a^2$ in seconds, whatever the length of the pendulum is; the amount of which you may easily calculate from the fact that if $a = 2°$, as usual in clocks, its numerical value is ·035, and therefore K = about 6 seconds. But this is more than what is called the circular error in a clock pendulum; for we need not care what is the difference between the time of a cycloidal arc and the actual circular arc which the pendulum describes, but only between such two small circular arcs, a and a_1, as the pendulum is likely to describe in different states of the clock. This quantity, which we may call ΔK, is only $5400\,(a^2 \sim a_1^2)$; and if we assume the larger of the two arcs to be as much as $2\frac{1}{2}°$ and the smaller $2°$, the circular error between them will be rather less than 4 seconds a day. This is a very large variation of arc for a tolerably good clock, and when it is as small as it generally is, the circular error may be expressed by differentiating the expression $5400\, a^2$, and we may say (so long as both the arc and its variations are small, remember) that $\Delta K = 10800\, a\, da$ (da being the variation of the arc). Thus if $a = 2°$ and $da = 10'$, ΔK will be very nearly 1 second: *i.e.* the clock will lose a second a day for such an increase of the arc, independently of any other

effect, either by way of increase or counteraction of the circular error, which may be produced by the escapement at the same time.

For the common purpose of finding the length of a pendulum to beat seconds, or any other required time, we need not trouble ourselves with anything beyond the equation $t = \pi\sqrt{\frac{l}{g}}$, in which t is the number or fraction of seconds, and l is expressed in feet, because g means 32·2 feet (in this latitude), and π is 6·283 or the numerical value of 180°. Therefore in order that t may be 1 second, you will easily find by a little calculation that l must be 39·1393 inches; and having got that fixed in your mind, you may find the length of pendulum for any other time of vibration very easily by multiplying 39·14 inches by the square of the ratio of the intended time to 1 second. But to save trouble I will put down a few of the lengths most likely to be wanted.

SECONDS.	FT.	IN.	SECONDS.	INCHES.
$2\frac{1}{2}$	20	$4\frac{1}{2}$	1	39·14
2	13	$0\frac{1}{2}$	$\frac{3}{4}$	22
$1\frac{1}{2}$	7	4	$\frac{2}{3}$	$17\frac{1}{3}$
$1\frac{1}{4}$	5	$1\frac{1}{8}$	$\frac{1}{2}$	$9\frac{3}{4}$

These seconds, and the second used as the unit of time in all mathematical formulæ, are seconds of mean time; and as a sidereal day is shorter than a mean one in the ratio of ·99727 to 1, a sidereal pendulum must be shorter than a mean one in the square of that ratio, which makes the sidereal pendulum at Greenwich 38·87 inches. It has been suggested that a mean clock may be made to show sidereal time on another dial

with only an error of a second in 4 years, by the following means:—put a wheel of 247 teeth on the centre-wheel arbor of the clock (which always turns in an hour), and let it drive a wheel of 331 on an arbor which also carries one of 43; and if that drives one of 32, it will turn in a sidereal hour; that is, if the mean clock itself goes right. But you can have no sidereal seconds hand with it, at least none pointing to them exactly, as the hand can only move with every beat of the pendulum, which does not beat sidereal seconds; and the suggestion is on the whole more ingenious than useful; for the reducing of one time to the other is done quite as readily and more exactly from an annual table kept for the purpose.

Centre of oscillation. It must be remembered that these are only the theoretical lengths of *simple pendulums*, with all the weight concentrated in the centre of the bob, and that this theoretical length by no means coincides with the actual length down to the centre of gravity of the pendulum, but is always longer. This length may properly be called the *radius of oscillation*, as the lower end of it is always called the centre of oscillation; which is not a fixed point in the body, like the centre of gravity, but a relative one, every axis of suspension having a radius and centre of oscillation of its own. It is not always a simple process to calculate this length (which we may as well called l) for any given pendulum, as it requires either the integral calculus or some rules deduced from it; but it will be easy to explain the nature and meaning of the quantities on which it depends. Let m be the mass of each particle of the pendulum, which in these

calculations must not be confounded with the weight, which is written mg (g being the force of gravity), r the distance of m from the axis of suspension, and M the mass of the whole pendulum; then the radius of oscillation = the sum of each particle multiplied into the square of its distance from the axis, divided by the sum of each particle multiplied into its distance simply; that is to say, $l = \frac{\Sigma m r^2}{\Sigma mr}$ (Σ being used to indicate this kind of summation, which can only be performed by integration except in very simple cases).

The numerator in this fraction is called the *moment of inertia* of the body with reference to that axis of suspension. Of course there is some quantity k^2 which $= \frac{\Sigma m r^2}{M}$, and k is then called the *radius of gyration* for that axis, and Mk^2 is obviously the moment of inertia again. In like manner some quantity $h = \frac{\Sigma m r}{M}$, and h is then the distance of the centre of gravity of the whole pendulum (not of the bob, remember,) from the same axis, which is easy enough to find in bodies of the shape commonly used for pendulums. It appears then, that the effective length l of a pendulum always $= \frac{k^2}{h}$; and it is only when the rod is very thin and the bob itself small but heavy, that k and h can be assumed to be even approximately identical, and therefore both $= l$, as they are in a simple pendulum. But it does conveniently happen that the centre of oscillation in clock pendulums of the usual forms is generally near the centre of gravity of the *bob*, and

sometimes exactly coincides with it, as we shall see presently.

This quantity Mk^2 the moment of inertia, always appears in mathematical formulæ as the resister of forces of rotation or vibration on an axis, and of all disturbances of such forces after they have once set the body in motion, and therefore we see at once why long and heavy pendulums are better for clocks than short ones. There are a few other simple propositions relating to the centre of oscillation, and the theory of pendulums, which it will be appropriate to notice here.

Draw a pendulum of any shape you like, supposed to be vibrating in the plane of the paper, and call its centre of suspension S, and its centre of gravity G, and the distance between them h. All bodies have this property, that their moment of inertia round any axis through G (which we call Mk_1^2) is less than round any other axis parallel to that, and we are not concerned with any but parallel axes; and further, if the other axis is distant h from the centre of gravity, the k^2 round that new axis $= k_1^2 + h^2$. Therefore if O, somewhere below G, is the centre of oscillation corresponding to S, l or S O $= \frac{k_1^2 + h^2}{h}$; and $l - h$, or G O $= \frac{k_1^2}{SG}$, or the centres of suspension and of oscillation are reciprocal. In fact, if the pendulum is wide enough, you may draw two circles round G with radii G S and G O, and if you stick an axis through the pendulum, at right angles to the same plane of vibration, anywhere in either of those two circles, it will vibrate in the same time as on the original S. Consequently, if you construct a pendulum (symmetrical on both sides of its middle plane

of vibration, to prevent it swinging with a twist) with one fixed axis S, and another adjustable one for O, and a moveable weight to adjust the time by, you can make it vibrate in the same time on both axes; and by adjusting the moveable weight also, the pendulum can be made to agree with the vibrations of a clock pendulum which is beating seconds; and then the distance between S and O, or the two knife edges which represent them, being measured, we shall know that that is precisely the length of the imaginary simple pendulum which would vibrate in the same time. It has also been proved that if round axes are used instead of knife edges, the distance between them (not their centres) equally represents the radius of oscillation.

If all the standard yard measures in the kingdom should ever be lost, they could only be restored by this process, according to an Act of Parliament, 5 Geo. IV. c. 74, which declares that a yard is $\frac{36}{39{\cdot}1393}$ of the length of the pendulum which vibrates mean seconds in London at the level of the sea, in a vacuum. As the force of gravity decreases towards the equator, an English pendulum would lose $2\frac{1}{4}$ seconds a day there. The following simple rule for the length of the seconds pendulum in any latitude has been deduced from observation, near enough for all practical purposes: $l = (1 - {\cdot}0027 \cos 2\text{ lat.})\,39{\cdot}1156$ inches; that number of inches being the length of the pendulum at lat. 45°. You observe that when the latitude is more than 45°, cos 2 lat. becomes −, and so l exceeds its length at 45°, as of course it ought to do.

The length of the seconds pendulum in northern latitudes is so near that of the French *metre*, of 39·371 English inches, that they are apt to be confounded. That standard however had no such origin, but was invented in their revolutionary desire to impose their measures upon all the earth, on the ground of its being the ten-millionth part of a quadrant of the meridian—about as practical a standard as the distance of the moon from Paris. Nevertheless, some persons in England have lately started the affectation of writing their measures in these foreign metres, and their decimals, instead of the old measures, which everybody who has to use them knows pretty well by sight, and carries in his eye, and which could not be altered without infinitely worse interference with the everyday business of life, than the lately exploded scheme for altering the lower divisions of the coinage, wherein nearly everybody agreed that the old *standard* must be kept. There can be no doubt too, that the yard originally grew up as the standard of length, because of its real convenience, and its coincidence with several natural measures. It is the length of a good stride of a man of what is commonly considered the most perfect height, and that height is two such lengths, and so is the stretch of his arms, and a yard is the natural length of his walking stick. The metre is properly the yard of a nation of giants. All this, observe, has nothing to do with the use of decimals of a yard wherever people find it convenient; for they can do that just as easily with a yard of 36 inches as with one of 39·37.

Shape of pendulums. It is convenient to know that the k_1^2 of an uniform rod with reference to an axis

across the middle of its length $= \frac{h^2}{3}$ if the length of the rod is $2h$; and as the distance of its centre of gravity from its end is here of course the same h, the radius of oscillation from the end is $\frac{4}{3}h$, or $\frac{2}{3}$ the length of the rod, since l always $= \frac{k_1^2 + h^2}{h}$. If the rod is fixed by the side of another longer one, with their two lower ends connected, as the compensation rods of a pendulum are, still the k^2 for the short rod $=$ its $k_1^2 +$ the square of the distance h (not the same h as before) of its c.g. from the top of the pendulum; and the same rule holds for the bob, except that its k_1^2 will be different according to its shape; in a cylindrical bob standing vertically, of radius b and height $2d$, $k_1^2 = \frac{b^2}{4} + \frac{d^2}{3}$. For any small pieces of the pendulum, such as collars, nuts, &c., it is sufficient to take their k and h simply as their distance from the pendulum top. In a pendulum of this construction then, we now have all the materials for finding the radius of oscillation l; for it will be expressed by a fraction, of which the numerator is the sum of the Mk^2's of all the different parts, which are easily calculated from these data (the previous integrations for each part according to its shape having been performed for you behind the scenes), and the denominator is the sum of all the Mh's, and M in both cases is measured by the weight of each piece of the pendulum.

Whatever the shape of a pendulum is in other respects, it is essential that the back and front should be alike both in weight and shape; or to speak

mathematically, that it should be symmetrical on each side of the middle plane of its vibration, or it will *wobble*, and vary its time in some irregular and incalculable way. It does not signify however, if one side of the bob is larger than the other in the direction of vibration; but as that would look ugly and the other does not, one never sees the ugly but innocent deviation, but frequently the other; for the pendulums of common clocks are often unsymmetrical in the back and front, and are therefore bad ones, though perhaps as good as the clocks they belong to. For this reason the old fashioned lens-shaped bob, or the flat cheese shape which most of the clockmakers use for church pendulums, are not good ones, because it requires great care to fix them with their own middle plane exactly coinciding with the plane of vibration. Even a sphere is not so good as a longish cylinder of the same weight, because it must be much wider, and therefore a slight error in making the hole for the rod, or any looseness in the hole, will throw the bob farther out of the symmetrical position than in a cylinder. Accordingly, cylindrical bobs are now used in all the best clocks, and it is better also to make the tops of turret clock pendulums domical, to prevent bits of dirt (or 'matter out of its proper place') from lodging upon them, which would alter the time.

An iron bob of this shape, 9 inches wide and 15 high, weighs 2 cwt. 14 lbs., and a $1\frac{1}{2}$ second zinc compensated pendulum with such a bob measures exactly 8 feet to the bottom of it. A $1\frac{1}{4}$ second pendulum with a bob 13×8 inches is 5 feet 9 inches to the bottom of the bob; and a regulator pendulum with a cylindrical

lead bob (not domed) 8 × 2 inches is ·43 inches to the bottom. I think it is a mistake to put these lead bobs in brass cases, as they usually are, for it increases the bulk and the resistance of the air, more than it does the weight, and is of no use whatever, and some expense.

Short and slow pendulums. There is a kind of pendulum which is properly enough used in the instrument called a *metronome*, for counting the time in music lessons in a way that requires no particular accuracy, and occasionally, but very improperly, used for small clocks. It follows from the propositions I have been explaining, that if a pendulum with a rod of sensible weight is set vibrating on an axis very little above its c. g. it will vibrate slowly, like a scalebeam; and consequently you may have a 2 seconds pendulum in the compass of a few inches. But even if the weight of it were equal to that of a large pendulum, its regulating power, or power to resist disturbance, would be very much less, because that is measured by the moment of inertia Ml^2, and therefore increases not merely with the length but the square of the length. The time of a metronome pendulum is adjusted by a small sliding weight on the rod above the axis of vibration, the bob being of course below it. Moving the weight up brings the c. g. of the whole nearer to the axis, and also increases the Ml^2 of the whole, and so in both ways makes it go slower, and *vice versâ*. It is kept going by a roughly made watch movement and a common recoil escapement, such as I shall describe presently for clocks.

COMPENSATION OF PENDULUMS.

All the foregoing propositions about the centre of oscillation may seem of very little importance to those who only know that most clock pendulums consist of a wire, or a light wooden rod, and a bob of no great size, and that the length required to beat any given time can therefore be found nearly enough by the rule that the time varies as $\sqrt{\text{length}}$, and then adjusted by trial. But there is another condition which has to be satisfied by the pendulums of all clocks pretending to accuracy; and with which the centre of oscillation has a great deal to do, and must be distinguished from the centre of gravity. That condition is that the pendulum must preserve the same effective length or radius of oscillation, however its real length may be increased by heat or shortened by cold, as it will be whatever it is made of; and it is evident that the place of the centre of oscillation must be known before we can make any calculations or contrivances for keeping it in the same place. If l is the effective length of the pendulum and dl the very small increase of it for any given increase of temperature, and dt the corresponding increase of time, then $\frac{t + dt}{t} = \frac{\sqrt{l+dl}}{\sqrt{l}} = 1 + \frac{dl}{2l}$, since $\left(\frac{l}{dl}\right)$ is so small that it may be neglected; or $dt = \frac{tdl}{2l}$, and the daily loss of the clock will be $43200 \frac{dl}{l}$ seconds. The following values of $\frac{dl}{l}$ for 10° of heat are given in the

books for the various materials which can be used for pendulums:

White deal	·000023
Flint glass	·000048
Steel rod	·000064
Cast iron	·000066
Iron rod	·00007
Brass	·00010
Lead	·00016
Zinc	·00017
Mercury (in bulk, not length)	·0010

Therefore a common pendulum with an iron rod will lose 43200 × ·00007 = 3 seconds a day for 10° rise of temperature, and if adjusted to go right in winter will lose about a minute a week in summer, unless it happens to be counteracted by some error of the clock in the other direction. Now assuming for simplicity of explanation, that the weight of the rod is immaterial, it is evident from the above table that if you set a brass tube of 6·4 feet on a nut at the bottom of a steel pendulum rod of 10 feet, and fix the bob to the top of the tube, it will keep at the same height under any variation of temperature, since the steel rod will let it down only just as much as the brass column raises it. But this would be a very inconvenient way of making a pendulum, with a tail below the bob more than double the length of the rod above it; and the same effect may be produced by breaking the lengths up, so as to get them all above the bob, taking care that the most expansive metal is always placed so as act as a

column and the least expansive as a wire. This was the old *gridiron* pendulum, invented by Harrison, the carpenter, who afterwards became a celebrated clock-maker early in the last century. The central steel rod has a broad nut screwed to the bottom, from which two stiff brass rods rise, one on each side, and they carry a cross head at their top, with a hole for the central rod to go through, and from it hang a pair of steel rods or wires, with a longer cross head screwed to their lower ends, from which rises a second pair of brass columns carrying a still longer cross head from which hangs a second pair of steel rods, and they carry the bob. The length of the central rod and the two pairs of steel rods together must be in the ratio of $\frac{100}{.64}$ to that of the two pairs of brass rods together; and it is easy to see that that cannot be done within the length of the pendulum with a less number of rods than nine. In fact, if iron was used instead of steel it would require two more pairs. Of course it is the same thing if tubes are used instead of each or any pair of rods, which was the form given to this pendulum by Troughton the optician.

But all these rods together have a very considerable weight of their own, and the assumption that either the centre of gravity of the bob, or of the whole pendulum, may be taken as nearly identical with the centre of oscillation, becomes practically as well as theoretically too erroneous to be admitted. The first effect is that the total length of the visible pendulum has to be increased, because loading the rod of a pendulum above the bob accelerates it; and then, when you have got

a near approximation to the proper length of the whole, the lengths of the compensation rods or tubes, and the bob itself have to be calculated so as to keep, not the centre of gravity, but the centre of oscillation at the same height always. It is stated however, that the centre of gravity of the bob in Troughton's pendulum was only ·4 inch below the centre of oscillation, the bob being of the lens form.

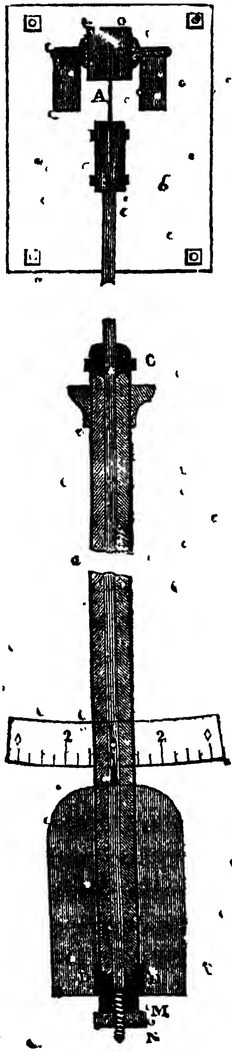
Fortunately it is not really necessary, or even advisable, to calculate the lengths of all the parts of a compensated pendulum in this way, which would be a very serious operation. It is not advisable, because these tabular rates of expansion cannot always be relied on, something depending on the working of the metal; and it is not necessary to calculate more than a first, or at the most a second approximation, because the final adjustments can be easily made by trial, and must be, for the reason just now given. Gridiron pendulums are now quite obsolete, and therefore it is unnecessary to give details of their lengths. Some of them may be found in the volume on Mechanics by Captain Kater, in *Lardner's Cyclopædia*, besides some other constructions of pendulums which I do not think it necessary to describe here.

Zinc and Iron. The compensation which is most analogous to the gridiron is the most recent of all, made of zinc and iron, which would no doubt have been invented long ago if the mode of working zinc had been known. You see from the table that if zinc is used instead of brass, the sum of the iron rods must be to the zinc as 17 to 7, or the zinc = ·41 of the iron, (reckoning of course each pair as one column or rod);

which will enable you to do with only one length of zinc and one length of iron rods or tube besides the principal rod. And as the zinc column is necessarily of the same length as the rods or tube which hang from it down to the bottom of the bob, we shall have this equation for finding the length z of the zinc, and of the iron tube also (calling the main rod r from the point of suspension to the nut at the bottom): $z = \cdot 41\,(r + z)$, which gives $z = \cdot 7r$.

This indeed is not strictly correct, because the bob has an expansion of its own, and if it is of iron it is the same as if the iron tube was attached to the bob at the centre of oscillation, which we shall see generally coincides pretty nearly with the centre of the bob except when the tubes are very heavy. But on the whole, this rule, that the zinc tube should be $\cdot 7 \times$ the length of the main rod, very nearly agrees with what is found by trial to be the right proportion in pendulum rods of various lengths, from 15 feet down to $3\frac{1}{2}$; except that in long pendulums the rods and tubes are generally thicker in proportion than in short ones, and consequently the centre of gravity of the bob (not of the pendulum, which is always above O, remember) has to be farther below the centre of oscillation O, and z has to be ($\cdot 71$ or $\cdot 72$) $\times$ the length of the rod. In the Westminster pendulum the c. g. of bob is nearly 8 inches below O, as will be more fully given hereafter; in an 88 inch pendulum with a bob 15 inches high and 9 inches wide the c. g. is $2\frac{1}{2}$ inches below O, and only about $\frac{1}{2}$ inch below in a 39 inch pendulum with a lead bob 8×2 inches, and there the zinc tube is exactly $\cdot 7r$. I may observe that the zinc must be drawn

Fig. 8.



and not cast, or its expansion cannot be relied on, as the metal is too soft and porous; and also that holes must be made in the outside iron tube to let the air reach the zinc, or the compensation will lag behind the changes of temperature. The rod and tubes should not quite touch each other, or at any rate should fit very loosely, so that the friction between them may not impede their free motion over each other. This is managed in large pendulums by two grooved collars C and M, one screwed into the top of the iron tube and resting on the zinc, as shown in fig. 8, and the other resting on the nut N at the bottom of the main rod and carrying the zinc; and there should be a pin through a slit in the rod to keep that collar M from turning with the nut. The iron tube has a thick collar D screwed on to it at the bottom, which fits into a hole in the bob. This kind of compensation pendulum is so easily made, and so superior to all the others, except the much more costly mercurial one, that it ought to be applied

to every clock which is expected to keep good time and is exposed to the natural variations of temperature.

Smeaton's pendulum. I have a clock with an old 1 second pendulum by Holmes, a celebrated clockmaker of the last century, with the following compensation, which was invented by Smeaton the great engineer. The rod is of glass, 43 inches long + 2 inches of steel spring, and on a collar screwed to the bottom of it rests a thin zinc tube $12\frac{2}{3}$ inches long, from the top of which is hung an iron tube of the same length, by the end being merely turned over, and on the bottom of that tube turned outwards rests a lead bob also of the same length, enclosing the tubes, so that the pendulum looks simply like a glass rod with a lead bob. The c. o. of the pendulum is 6 inches from the bottom of the bob, and therefore the expansion of 6 inches of lead + that of the zinc tube upwards, has to balance that of the glass rod and the iron tube downwards, as you may calculate from the table that it will very nearly.

Wood and Lead. If the expansion of wooden rods could be depended on, or if it were not modified by absorption of moisture, or something else which renders their action uncertain, the simplest of all compensation pendulums would be a wooden rod with a lead bob 14 inches long. But in spite of all attempts to make the rod damp-proof, it appears that every body who has tried the experiments carefully has come to the conclusion that they are capricious. Nevertheless, they are far better than an uncompensated iron rod. The rods of long church-clock pendulums are generally much too thick, and thereby contain a much larger bulk of absorbing matter than they need. A deal rod of

elliptical section $\frac{3}{4}$ inch × 2 inches will bear above 2 tons, and therefore there is no pretence for making them any thicker.

Mercurial pendulums. The principle of the steel and mercury pendulum, which was invented by George Graham a clockmaker in 1715, or thereabouts, is just the same as of the wood and lead. The common form of it is a steel rod ending in a stirrup carrying a glass jar of mercury, which is generally of 2 inches diameter, and then the mercury has to be $6\frac{1}{2}$ inches high, and its centre of gravity or of height is below the centre of oscillation. It must be remembered in calculating the height of the mercury, that it has a lateral expansion of its own in the square of the ratio given in the table for the linear expansion of the glass, or whatever else the jar may be made of: no metal except iron will do, as all the others would be amalgamated with and gradually dissolved by the mercury. It may save trouble to any one who means to make the calculation to remind him that the expansion is so small that instead of squaring the long line of decimals in the table you need only multiply it by 2, and by 3 for the cube: thus the square of the ratio for the 10° linear expansion of iron, $(1{\cdot}000066)^2$ to 1, may be taken at 1·00013 for the increase of the capacity of an iron cylinder sideways; and this deducted from the absolute or cubical expansion of the mercury ·001 will give the ratio of its rise, and that ratio multiplied by the height of the c.o. of the pendulum above the bottom of the mercury ought to = the descent of the c.o. by reason of the expansion of the steel rod.

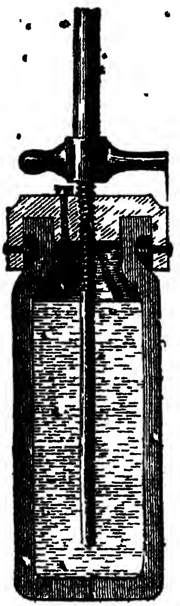
It is not worth while to go through the calculations,

because the thing must be finally adjusted by experiment, and one great advantage of the mercurial pendulum is that it can be adjusted so easily. Mr. Dent, who has long used only iron jar pendulums in his astronomical clocks, finds that the height of mercury required in them is 6·8 inches, and the weight about 12 lbs. and the bottom of the jar is 43½ inches from the top of the pendulum. The advantages of the iron jar are the greater compactness of its shape, the rod being simply screwed into the cap without the clumsy looking apparatus of a stirrup—its portability, compared with a glass jar pendulum of the common kind—the power of heating the mercury in the jar so as to drive off air bubbles—and the complete contact between the two principal materials of the pendulum, for the rod also plunges down into the mercury. Nevertheless, no other London clockmaker will use these pendulums, so far as I have seen, though the old ones have not one single point of superiority over them, except being rather cheaper; which however is of little consequence in the price of a good astronominal clock, which runs from 40*l.* to 80*l.*; and in such clocks more than the whole cost of the pendulum is generally thrown away in work for which the clock is not really worth one farthing more as a timekeeper.

Several different forms of the glass jar pendulum have been proposed for avoiding the objections to the common form, and the expense of the iron jar. Captain Kater's, described in vol. 130 of the *Philosophical Transactions*, with his escapement, is the simplest, consisting merely of a glass jar with a flange or rim round the top, which is hung to a solid iron cap by

a screw ring surrounding the cylinder; the rod goes through the cap. He had a glass rod, but a steel one would be better and easier to make, requiring no cementing to the glass, as all the other plans do, of glass jars without a stirrup: in one of them, patented by Mr. Loseby, the rod has to move through a stuffing box at the bottom also. Kater's also makes the top of the jar inconveniently large; but that might be got over by contracting the jar above the mercury and a little below the top, and making the ring in two pieces. The whole would then assume this form, of which the construction is obvious. The short cross piece just above the jar is a handle pinned to the rod, to hold it by when you turn the jar to regulate the length of the pendulum, and an index comes down from it to the divisions on the cap. There should be a small hole in the cap, with a screw plug, for adjusting the quantity of mercury, which will require rather less height than in a stirrup. The only thing requiring care in making this pendulum would be the fitting of the cap and ring to the jar flange, which would easily be turned or ground true by setting the jar on a chuck in a lathe. A piece of greased leather should be fitted in tight between the jar and the cap.

Fig 9.

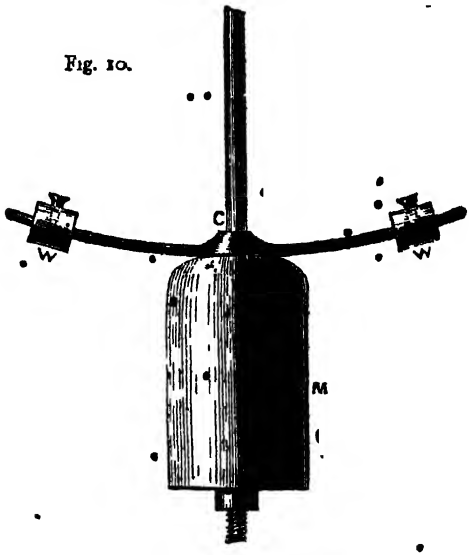


I shall have another partial mercurial compensation

to notice after the calculations for pendulum regulation, which are necessary for understanding it.

Compound bar compensation. This is one of a totally different character, and is founded on the principle of the compensated balance in watches. W C W is a compound bar of brass and iron or steel brazed together with the brass side downwards. As brass expands more than iron, the bar will bend upwards as it gets warmer and carry the weights

Fig. 10.



W W with it, and they may be so adjusted both by magnitude and position as to raise the centre of oscillation as much as the elongation of the pendulum rod lets it down. I cannot give any details of the proportions, as this plan does not appear to have been used in England except in experiments, and Mr. Dent

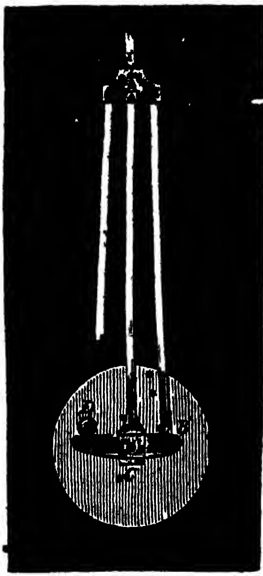
tells me it was found inferior to the other methods, over which I do not see that it has any advantage except the facility of adjustment. It is said in Kater's treatise to have answered in France, but the French seem to prefer complicated compensations to simple ones. It might however be used to complete the adjustment of another compensation left imperfect for that purpose, in which case the weights would only need to be very small.

Homogeneous compensation. All the compensations I have yet mentioned require the use of at least two substances of different expansibility; but there is one which does not; and though it is practically of little or no value, in any form in which it has yet been made or suggested, it is worth while to describe the principle of it. If the pendulum spring is drawn up through a close slit in the cock, as much as the pendulum lengthens by heat, its effective length will remain the same; and this may be done by various arrangements, of which the simplest is hanging the spring to another cock above the slit one, set on the top of a stiff bar long enough to expand upwards as much as the pendulum rod expands downwards. This bar may be either of the same or of a different metal from the pendulum rod, and its length will of course depend on its material; or the slit cock may be on one end of a lever, of which the other is pulled down by a wire of the same length and metal as the pendulum rod. But there is a serious objection to this plan in every form: if the slit is loose enough to let the spring slide up and down through it, it is too loose for the proper action of the pendulum, which we shall see hereafter

absolutely requires a firm fixing of the point of suspension. Nearly all the French turret clocks in the Exhibition of 1851 which had any compensation had this in some form or other. I think there was not one with a zinc compensation pendulum.

Ellicott's pendulum. There is another bad one which is still used in small French clocks, though it has long ago been abandoned in England where it was invented, by Ellicott a clockmaker in the last century. A C the main rod is of iron or steel, and it has a pair of levers set on a cross pin at the bottom, of which only one B C D is shown here: at A there is a strong collar fixed to the rod, and between that collar and the short arm of each lever stands a stiff brass rod. The bob hangs by two pins, of which D is one, on the long arms of the levers; and it is evident that by a proper adjustment of the levers the bob may be made to rise under the expansion of the brass rods just as much as the expansion of the iron rod lets down C, the axis of the levers. But this action involves considerable friction at D, and the pressure on the ends of the brass rods must very much exceed the weight of the pendulum, and it is said to move by jerks, and is altogether inferior even to the old gridiron.

Fig. 11.



and much more, to the zinc or mercurial pendulum, besides being much more difficult to make properly. I suppose they are only made because they have a kind of scientific look to ignorant people, in clocks made to show and to sell.

REGULATION OF PENDULUMS.

After a pendulum is made as nearly as possible of the proper length, it is necessary to have some means of adjusting it, so as to swing exactly in the proper time, and the adjustment itself may require altering from time to time according to changes in the state of the clock. This is done very simply by a nut at the bottom of the rod, or the principal rod if there are several, by which of course you can raise or lower the bob, with the compensation rods if there are any. In the better class of pendulums the nut is made with a large graduated head and an index over it to mark how much you turn it; and if you know what alteration of time is due to one turn of the nut, you can subdivide it as you want. If the length of the whole rod is called l and one turn of the screw dl (being very small in proportion to l), it will alter the time $43200 \frac{dl}{l}$ seconds a day, the calculation being exactly the same as that at page 51, for the alteration by temperature. So if the threads are $\frac{1}{16}$ in. apart, and the rod 43 inches long, one turn of the nut will just alter the clock a minute a day.

But this mode of occasional regulation is inconvenient, especially for large pendulums. Even small ones it is better not to stop and disturb if you can help

it; and raising the heavy bob of a large pendulum is an unpleasant operation and requires some special provision to avoid twisting either the compensation tubes or rods, or worse still, the spring at the top. Accordingly, Mr. Dent used to have his turret clock-pendulums set a little too slow by the screw, and then raised them up to the proper time by laying small weights on the top of the bob; and he put a small sliding weight on the rod of his 'regulators' or astronomical clocks. But there is a better plan than either of these, which is now used in all the best turret clocks. The pendulums of astronomical clocks are seldom regulated to any great nicety, but the rate is tried from time to time by observations and registered. The mode of regulating by small weights is this:—

There is a certain place in the rod where the addition of a small weight accelerates the pendulum more than anywhere else, and it may be proved by the theory of *maxima* and *minima* (which involves the differential calculus) that that place is the middle of the length l the radius of oscillation. And further, any moving of the weight a little way up and down near that maximum point produces no sensible effect on the time, and for that reason the sliding weight plan is a bad one, besides involving the stopping of the pendulum. The safest way of finding what small weight must be laid on a collar fixed at or near the middle of the pendulum to accelerate it by any given amount, is to put on a weight large enough to produce some considerable error in a day, and try what it is by another good clock, and then divide it for smaller corrections. The calculation for it is as follows:—

Let t be the old time, and t_1 the new, due to the addition of a small weight mg at the distance d from the top of the pendulum, M representing the mass of the whole pendulum as usual; then according to the rules given at pp. 40, 44, $t_1 = \frac{\pi}{\sqrt{g}}\sqrt{\frac{Ml^2 + md^2}{Ml + md}}$; and as $t = \pi\sqrt{\frac{l}{g}}$, if you expand the numerator and denominator of this fraction by the binomial theorem, neglecting terms smaller than $\frac{d^2}{l^2}$, you will have $t - t_1 = \frac{md}{4Ml}$.

Therefore if $d = \frac{l}{2}$, the daily acceleration ΔT will be $\frac{86400m}{8\,M}$; or a weight $= \frac{M}{10800}$ = an ounce on a pendulum of 6 cwt. laid on a collar half way down the rod will accelerate it a second a day. If the collar is only at the distance $\frac{l}{3}$ from the top, the weight must be $\frac{M}{7200}$ to do a second a day, or very nearly 1 grain to a pound (av.), which is 7000 grains. These small weights can easily be put on or taken off without disturbing the pendulum; and if you have a set of them marked $\frac{1}{4}$, $\frac{1}{2}$, 1, 2, 4, according to the number of seconds a day by which they will accelerate, you can make any regulation of it for a range of errors amounting to 8 seconds a day; for anything beyond that you must alter the regulating screw at the bottom. It should be set to lose a little without any of the small weights, so that there may always be some of them on and therefore some ready to take off if the clock gains.

There may be cases where it is more convenient to regulate the pendulum by laying the weights on the top of the bob. The principle is just the same, but the weights have to be larger, and the risk of disturbance is greater. In that case the calculation will be, supposing b to be the distance of c.o. below the top of the bob, $t_1 = \frac{\pi}{\sqrt{g}} \frac{\sqrt{Ml^2 + m(l-b)^2}}{\sqrt{Ml + m(l-b)}}$; expanding this as before, and neglecting mb^2 now as the small quantity, we shall have ΔT the daily acceleration $= \frac{43200mb}{Ml}$ in seconds. To compare this practically with the other plan, suppose $b = \frac{l}{12}$, which is as much as it is likely to be, then $\Delta T = \frac{3600m}{M}$ instead of $\frac{10800m}{M}$; or the regulating weights must be just three times as large to produce the same effect on the top of the bob as half-way up the rod.

Mercurial tube compensation. This suggests another possible mode of compensating very long pendulums at little more expense than short ones. If a small piece were taken off the bottom of the bob and put on the rod at half its height, we should be accelerating the pendulum in both ways. And the pendulum can be made to do this for itself, by making a cistern for mercury in the bottom of a long cast iron bob, with a thin tube rising from it and ending in a bulb half way up the rod. The mercury should just reach the bulb in the coldest weather, and then more of it will be squeezed up out of the cistern into the bulb as it gets

warmer. We know that an iron rod pendulum will lose three seconds a day for 10° of heat, and also that if a weight m is transferred to the bulb from the bottom of the bob (b being assumed to be $\frac{l}{12}$ as before), ΔT will $= \frac{m}{M}(10800+3600)$; therefore for 3 seconds, m must $= \frac{M}{4800} = \cdot 0002M$ nearly; which must be the excess of expansion of the bulk of mercury above that of the iron cistern itself. This excess for $10^\circ = \cdot 0008$. Therefore if the mercury is about $\frac{1}{4}$ of the weight of the whole bob it will do the compensation in this way. The pendulum rod should be a tube large enough to inclose the mercurial one and its bulb; and the cistern should have a large screw-plug to adjust the quantity of mercury that it will hold. I do not mean to say that this plan would be worth adopting for pendulums of such lengths as can be easily managed with zinc tubes; but the difficulty of making them stiff enough increases rapidly with the length and weight of the pendulum: and at any rate the principle of such a possible compensation is worth knowing.

SUSPENSION OF PENDULUM.

Pendulums for experiments on their own time or on the force of gravity (such as the Astronomer Royal's experiments in the Harton coal mine in 1854 to calculate the weight of the earth), are always suspended on knife edges like a scalebeam, because the usual suspension by a spring affects the time of vibration to some

extent, however thin it may be. Such pendulums are not connected with clocks, but set swinging by themselves and compared with an adjacent clock pendulum for counting their vibrations. This suspension will not do for clocks, because the knife edges and the planes which carry them wear out of shape, however they are made; and it is also difficult to keep the axis of motion exactly in the same place.

The late Mr. Vulliamy, under some strange misapprehension of a passage in a French book about chronometer springs, took it into his head that heavy pendulums ought to be hung on portions of large friction wheels, which certainly do involve a very small amount of friction, provided the rolling faces are kept very clean and well oiled. But the expense is so great and such delicacy of adjustment is required that he was only able to do it in two instances, and to propose it in his plan for the Westminster clock. Since I described it in the first edition of this book I have seen it at work in the Post-office clock (for which he had 80*l*., and a better could now be made for 15*l*.), and I have also seen a great deal more of large clockmaking than I had then, and I am convinced that it is not only an useless but mischievous expense, however plausible it may appear. It was just worth recording as a warning against reinventing it.

The pendulums of small French clocks are often hung by a piece of string; why, I do not know, as it is certainly not better, and I should think not sensibly cheaper than a spring, which is used in the American clocks, which are the cheapest in the world, and are—or rather were until they became intolerably bad through

competition, much better than the great majority of the French ornamental clocks; of which I believe there are nearly as many in England standing still as going, and not a quarter of those that go can be depended on to five minutes a week.

The best mode of suspending clock pendulums is undoubtedly by a thin spring, as shown at p. 56; not that the elastic force of the spring is of any use, but it has the advantage of being perfectly free from friction. It is said in the article on clockmaking in the *Encyclopædia Metropolitana*, that a spring ·003 inch thick affects the vibrations of a pendulum of 14 lbs. less than any other spring either thicker or thinner. If this is so, it must be because a thinner spring is not merely bent but strained by a pendulum of that weight, which would soon break it in use. But other persons who have tried similar experiments say they found a different result, and that the thinner the springs are (so long as they are not visibly strained or *set*) the less they alter the rate of the pendulum from a free one on knife edges: which certainly seems to me more probable. It is essential that a pendulum spring should be quite uniform in all respects from one edge to the other, and also that the point of suspension should be firm and steady, which can only be secured by the *chops* which hold it being screwed closely to it and firmly fixed also themselves. And yet, with the usual preference of mankind for doing wrong when it is quite as easy to do right, it is very common to find the fixed chops thin and those of the pendulum top thick, which have no strain upon them and need only be thick enough to hold the screws.

In common clocks the cock from which the pendulum hangs is screwed to the back plate of the clock frame and has merely a slit in it, through which the spring hangs by a pin or rivet through its top. But in all the better class of clocks, either large or small, which have heavy pendulums for their size, the spring is screwed fast between two brass or iron chops as in fig. 8, and there is a large pin through them and the spring, with shoulders, so that it will just drop tightly into Vs in the two sides of the cock. The cock is then a much stronger thing than in common clocks, and is screwed to the back of the case, or the wall, or some other fixture, so that the 'movement' (or train of wheels) can be taken away leaving the pendulum hanging: sometimes the pin has nuts on the ends to adjust the place of the pendulum exactly. The Vs are very often made too acute, which just frustrates their object of leaving the pendulum free to adjust itself so that the top of the spring or the bottom of the chops may be exactly level. A very obtuse angle is obviously enough to keep the pendulum in its place, and nothing beyond that is required.

I have several times had letters complaining that people could not keep their pendulum springs from breaking. As they cannot all have been bad ones, I have no doubt the causes were, either the bottom of the chops not being level, in which case there is an unequal strain on the spring, which will make the pendulum swing unevenly at any rate; or else, and more probably, the edges of the chops being left sharp, instead of being just rounded off with a file, as the broken springs have looked as if they were cut. I

think the best way of letting the spring into the pendulum top is to cut a broad slit in it, and fill it up with the spring and two pieces of brass which will just fit it and then put two screws through the whole together. You cannot cut an even slit only just the thickness of the spring, unless the spring is much thicker than it ought to be.

A spring does not bend only at one point as a string does; and therefore a pendulum bob hung by a spring does not move exactly in a circle, but in something more like a cycloid described with that radius of curvature, as in fig. 7, p. 38; and it has often been attempted to make springs which would render the pendulum absolutely isochronous for all such arcs as it is likely to swing. Possibly the thing could be done, if it was worth doing; but both I and some other persons who have spent a great deal of time on experiments have come to the conclusion that it is not, for reasons which will appear when we come to consider the effect of the escapement on the time of vibration. Indeed. I may say at once, with respect to the only escapement I have yet described, and all others on the recoiling principle, that the circular error, which it is the object of these spring contrivances to correct, is already more than corrected by those escapements; for the clocks never lose, but gain, when the arc of the pendulum increases; so that the circular error is actually useful for counteracting the escapement error, and the clock goes better than it would with a perfect cycloidal pendulum, or any equivalent contrivance.

It is hardly necessary to say that the whole of the pendulum suspension should be so adjusted that the

bend of the spring may be exactly opposite the pivot of the pallet arbor, in order that the fork which embraces the pendulum, as described at page 36, may have as little friction upon it as possible. It must not however be tight, for the reason just now given, viz. that no point in the pendulum describes quite a circle, and the difference is sensible enough generally to stop the clock if the fork fits the pendulum rod too tightly. It is equally necessary that the plane of vibration of the pendulum should be exactly at right angles to the pallet arbor, or else there will be a sliding motion of the pendulum backwards and forwards in the fork. But obvious as these things are, they are all constantly neglected, especially in large clocks, where the friction of all the parts is also the greatest. The fork indeed is seldom left too tight, because that mistake tells its own story directly; but by way of making up for it, it is very often so loose that you hear the shake of it from one side to the other at every beat. There ought to be a drop of oil there, as that is just enough (if the fit is right) to keep a steady hold without either shake or tightness, since oiled surfaces are not really in metallic contact. Sometimes heavy pendulums are hung by two narrow springs instead of one broad and thin one, to secure the vibration in the proper plane; but it is a bad plan, because it is difficult to get the two springs equal in all respects. The springs of 'regulator' pendulums of 14 or 15 lbs. are generally about $\frac{1}{2}$ an inch broad and 2 inches long; I mean clear of the chops of course; that of the 6 cwt. pendulum at Westminster is 3 inches by 5 and $\frac{1}{60}$ inch thick.

There should always be a degree plate, with a pointer

to it on the pendulum wherever it can be most conveniently seen. The length of 4° on the plate is always ·07 × its distance from the top of the pendulum; and as the only use of the degree plate is to see that the pendulum keeps the same arc, or to see how it varies, no very great accuracy is required in the degrees.

ESCAPEMENTS.

Anchor pallets. The next important invention which followed that of pendulums, and that very soon, was a pair of anchor-like pallets moving in the plane of the scapewheel, instead of the 'vertical escapement' with pallets set across a crownwheel, which being very short required a long swing of the pendulum to let the wheel escape. It is not indeed absolutely necessary that crown wheel pallets should be very short, and they would go with less friction if they were long and the teeth of the wheel few; but the recoil would be more violent, and they would require more careful adjustment, and as a matter of fact they always were short. Anchor pallets in the form in which they were first invented, either by Dr. Hooke, whom I have already mentioned as one of the claimants of the pendulum, or by Clements, a London clockmaker of his time, had a recoil, no less than the crownwheel pallets, but they could be made to escape at as small an arc as you please. Fig. 12 is a drawing of the recoil escapement, as it is always called, which is still used in all the common clocks in the world, though it has long been abandoned in all that make any pretension to great accuracy.

In this drawing the tooth *a* has just escaped from the left pallet A, and *b* has dropped on to pallet B; the pendulum is therefore moving the left, and it will not stop immediately but will go on a little farther and so make the wheel recoil a little, as you may see clearly enough in any old-fashioned house-clock with a seconds hand: as it returns, the wheel urges the pendulum again to the right and so gives the impulse which is necessary to maintain its motion against the resistance of the air and the friction of the escapement itself; and then tooth *b* escapes and the tooth below *a* falls on A and the same action takes place there. You observe that I have drawn the acting faces convex. For some theoretical reasons they ought to be concave; but as very often happens in clockwork, the one practical reason of

Fig 12

friction preponderates the other way. Even if they are made flat, the teeth always wear holes in them, though the teeth are of brass and the pallets of steel, made as hard as possible, and it is evident that the friction at the recoil is much greater if the pallets are concave than convex. Moreover it is always found that as the pendulum arc decreases from any decrease of force in the clock, it loses, and *vice versâ;* and concave pallets would not diminish this error, but increase it. Some considerable persons stuck to this escapement for some time after the dead escapement was invented, being apparently misled by the fact that variations of force produce less variation of the *arc* in this than in the dead escapement, because the friction of the recoil checks the arc; but it does not follow that the variations of *time* are less: in fact it has been proved both by experience and calculation that they are not.

Harrison's recoil escapement had scarcely any friction. It was invented by him when he was a working carpenter in Lincolnshire. Any one who wants to see a description of it will find one in the 7th edition of the *Encyclopædia Britannica;* but I did not think it worth while to repeat it in the 8th; nor here, as it is a mere obsolete curiosity, and nobody else ever made it to answer, even before better things were invented. If such a thing were worth doing, it might be done much more simply by a three-legged scape-wheel, such as I shall describe as one form of the dead escapement (at fig. 16A), but without the horizontal or dead pallets there, and with the impulse pallets set deeper and not in the same line, though parallel to the pendulum. The impulse would be given with nearly

as little friction as it is there, and the recoil would also have very little; and, if the force on the scapewheel were made uniform, as it may be by a contrivance which I shall describe for turret clocks, there is no reason why such an escapement should not go very well, though the dead one would go better.

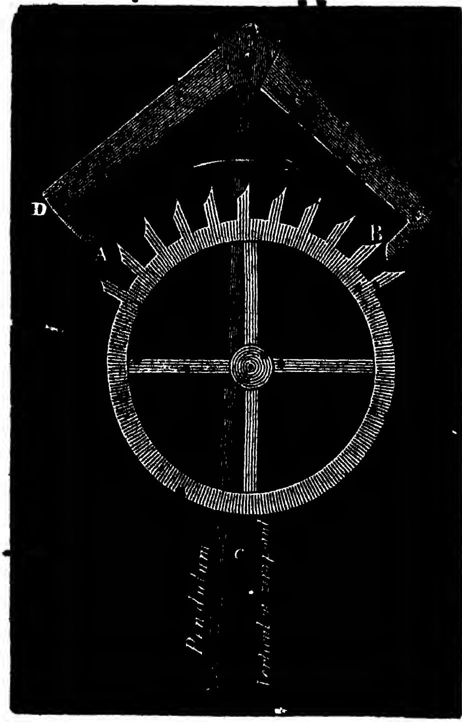
DEAD ESCAPEMENTS.

In fig. 13, as in fig. 12, a tooth of the scapewheel has just escaped from pallet A and another has just fallen on to pallet B; but the face on which it falls is very different, as the shape of the teeth also is, but that is only to give room for clearance, and in both cases it is only the point of the tooth that acts. Here you see the face of the pallet is divided into two, and one part is an arc of a circle of radius C B while the other part is much the same as it was in the recoil pallets. The consequence evidently is that there is no recoil here, and the tooth lies *dead* on the circular face B E (which is therefore called the dead face) however far the pendulum may swing, until it returns to B, and then the tooth begins to act on the impulse face and gives the impulse to the pendulum exactly as in the other escapement. In the same way the dead face of the other pallet is part of a circle with radius C D.

This is the dead escapement, which was invented early in the last century by Graham, who invented also the mercurial pendulum and the horizontal watch escapement; and the great advantage of it is, that although a slight increase of force on the scapewheel increases the arc of the pendulum, it does not sensibly increase

the time, if the escapement is properly made. This was first demonstrated mathematically by the present Astronomer Royal in the *Cambridge Philosophical Transactions* in 1827 (Vol. III. p. 105), and it may be made tolerably clear in a general way without any mathematics, as follows. If each tooth could drop exactly on the corner dividing the dead and impulse faces of the pallet, as at B, it is clear that the impulse on each pallet would begin and end when the pendulum is at the same distance on each side of zero or the vertical. In other words, as much of the impulse would be given while the pendulum is falling as while it is rising, and therefore its gravity would be increased on one side and decreased on the other through equal arcs and during equal times, and therefore on the whole the accelerating force on the

Fig. 13.



pendulum, and therefore its time of vibration, not altered. Neither would the friction on the dead faces, if it were constant throughout, and if it acted through the same arcs before and after zero, affect the time directly; for while the pendulum is falling the friction acts contrary to gravity, and with gravity while it is rising after the escape has taken place. As it is always resisting the motion of the pendulum it tends to diminish the arc; and on the other hand, the impulse always tends to increase it; so that here also there is counteraction to some extent; but as the friction on the pallets does not vary in any definite proportion to the force of the train, but sometimes one way and sometimes the other, no useful relation of this kind can be established. All we can say about the arc is that it increases under an increased force or a diminished friction, until the remaining friction on the pallets and the resistance of the air stops the increase.

Mr. Bloxam came to the conclusion, in his elaborate paper on escapements in 1853 in vol. 22 of the *Astronomical Society's Transactions*, that so far from the dead friction being a thing to be disregarded as constant and not materially affecting the rate of the clock, as Mr. Airy had assumed, it probably affects it more than all the other escapement errors together in an astronomical clock with even a moderately good train, and in a way which it is impossible to calculate on account of the different circumstances under which it varies. It is evidently very improbable that the friction can be made the same while the point of the tooth is (as we may say) ploughing its way up the pallet during the ascent of the pendulum and sliding down it in the

descent. Having said this I shall not attempt to deal any farther with the dead friction, but its existence must be borne in mind as capable of either mitigating or increasing the other errors, as the case may be; and some idea of the magnitude of its effect may be formed from this, that I have known the arc of a new church clock of Mr. Vulliamy's increase from 2°·30′ to 3°·30′ in the first year, from no other visible cause than the self-polishing of pallets.

Now let us apply the same reasoning to the recoil escapement, and we shall find that the result is just the opposite from that in the dead. That part of the impulse which is within the points where the teeth fall on the pallets is the same as in the dead escapement, and therefore may be taken not to affect the time; but in the ascending portion of the recoil the force is acting with gravity, and so it is in the descending portion. Whenever the force of gravity is increased the time of a falling or swinging body is diminished; and therefore on the whole any increase of the force of the clock in the recoil escapement tends to make the pendulum go faster. But the recoil resists the pendulum in rising as much as it impels it in falling, and by means of the friction, resists it much more; and as the force through the other portion of the arc, corresponding to the impulse in the dead escapement, tends to increase the arc, they may so nearly balance each other that an increase of clock weight may produce no visible alteration in the arc at the very same time that it is, as we may say, knocking the pendulum backwards and forwards more rapidly between the same limits; whereas the dead escapement just sends it so much faster as to make the

whole vibration take very nearly the same time while it has to pass through a longer space—subject to the following modifications.

The first of them is this: the teeth cannot safely be made to drop exactly on the corners of the pallets, but must have a little of the dead face to fall upon; and therefore the angle or arc of impulse before zero must be rather less than that after zero, and therefore the tendency to increase the time preponderates. For the same reason there is necessarily rather more of the dead friction in the descent of the pendulum, where it acts against gravity, than in the ascent, and so that also tends to slowness. The greater this difference is, or the higher up the dead faces the teeth drop, the greater these causes of error are; and yet it is very seldom that one sees a dead escapement whose maker appears to have had the least idea of this fact; for I suppose if they had, they would not make them as if they thought the right thing was for the tooth to fall as far over the dead face of the pallets as possible, instead of falling as near the corner as possible.

Another modification is the circular error, which I have already explained, and which acts in the same direction as the one last mentioned, increasing the time with the increase of the force and therefore of the arc.

But there is another of the opposite kind; for when the whole arc increases, that portion of the arc and of the time during which the impulse or disturbance of the natural time of vibration takes place becomes less in proportion to the whole, and that diminishes the increase of time which would otherwise be caused.

And yet further, we have hitherto assumed that

nothing varies except the force of the scapewheel teeth on the pallets, and the friction which is due thereto. But the friction on the pallets may and constantly does vary even more than the force of the clock, and generally in just the opposite direction; for as the clock and pallets get dirty together, the force on the pallets decreases, which accelerates the time, while the friction increases, which retards it; and so on the whole it is by no means certain which result will preponderate in the natural state of the clock, or by how much; and the only certain way to get a steady rate out of a dead escapement clock is to take as much care as possible to keep the force and the friction constant; which is only to be done, and can be done in small clocks with light wheels, by very accurate workmanship, highly finished and hard acting surfaces, and keeping them clean and just sufficiently oiled, and above all a good pendulum, properly fixed. It is necessary for this also that the two pivots of the great wheel should be as nearly equal as possible even at the cost of making the back one larger than it otherwise need be. I have frequently observed the arc to be sensibly greater at that end of the week at which the string is at the back end of the barrel, and therefore the weight acting principally on the thin pivot. When a pivot has to be used also for winding it must be made very much thicker than is required for a mere pivot, and I wonder that an auxiliary winding wheel is not used in very fine dead escapement clocks, as it is in large turret clocks, since it would enable the friction of the great wheel pivots to be considerably reduced. It could be made to push in and out of gear by a lever worked by a pin in the dial.

I may as well mention here that a 'steady rate' means, not necessarily that the clock is going *right*, but that it is going *uniformly*, or regularly gaining or losing exactly the same number of seconds a day or a week. The rate is always written + when the clock gains, and − when it loses; which you must remember is just the opposite of the signs appended to the expressions for the various errors of the time in the mathematical formulæ; for when t the time of vibration of the pendulum increases, dt is +, and the clock loses and the *rate* is too little or −.

Something more precise than the above general reasoning is of course necessary for actually measuring the different elements of variation of rate. This is what Mr. Airy did, or rather laid the foundation for doing, in the paper I have already referred to; and taking it up at the point where his calculations ended and his inferences began, I carried it farther in two papers in the *Cambridge Transactions* in 1848 and 1852 (vols. 8, 9). His calculations are rather too long and complicated to insert here, and they may be found in *Pratt's Mechanics* and perhaps some other Cambridge books; so I will take them up at the same point here.

The first important mathematical result arrived at by Mr. Airy was this: If ϕ is a disturbing angular force on a pendulum when it is at the angle θ after zero (reckoned + when it tends to increase θ), and a the extreme arc, then the increase of time of one vibration due to the disturbance, which we will call

$$\Delta = \frac{l}{\pi g a^2} \int \frac{\phi\, \theta\, d\theta}{\sqrt{a^2 - \theta^2}},$$

this integral being taken between the limits through which the disturbing force acts. He also found a corresponding formula for the increase of arc; but that is of no use towards ascertaining how much the arc really will be increased by the continual action of the disturbance, as it is soon limited by friction and resistance of air in a way which cannot be calculated.

Before we can make any use of this value of Δ we must see what ϕ is in the particular escapement. In order to do this let us call the angle which the impulse face of each pallet makes with the dead face δ; then, since the tooth, taken as a prolonged radius of the wheel, ought to be a tangent to the dead face, δ will be the inclination of the tooth to the impulse face at the beginning of the impulse; and for this purpose we may assume it to continue the same throughout, though in fact it increases a little.* Let p be the distance of each pallet from their arbor, and Pg the moving force of the clock-weight as it arrives at the points of the scape wheel teeth, Ml the mass and length of the pendulum (which we may treat as its equivalent simple one for this calculation); then the equation of motion will be

$$\frac{d^2\theta}{dt^2} = -\frac{g\theta}{l} + \frac{Ppg\tan\delta}{Ml^2},$$

since g tends to decrease θ after zero where it is +, and ϕ, which represents the other term in the

* If κ is the motion of the wheel on the pallet during each beat, the angle of the tooth with the pallet face will be $\delta + \kappa + \beta + \gamma$ at the end of the impulse on the down pallet, and $\delta + \kappa - \beta - \gamma$ on the up pallet: κ cannot be more than 5° in a 30-toothed wheel, and $\beta + \gamma$ is never more than $1\frac{1}{2}$°; and as δ is generally about 60°, the variation is too small to affect these calculations materially.

equation, does the contrary. And as this term is independent of θ, we have

$$\Delta = \frac{\mathrm{P}p \tan\delta}{\mathrm{M}l\pi a^2} \int \frac{\theta\, d\theta}{\sqrt{a^2-\theta^2}}.$$

The limits between which the integration is to be taken are from $\theta = -\beta$, where the impulse begins before zero, to $+\gamma$, some rather larger angle where it ends after zero; and the result will be

$$\Delta = \frac{\mathrm{P}p \tan\delta}{\mathrm{M}l\pi a^2} \left(\sqrt{a^2-\beta^2} - \sqrt{a^2-\gamma^2}\right).$$

Now before going any farther we may see at once from this, that if β could be made $=\gamma$, *i.e.* if the impulse could be made to begin just as much before as it ends after zero, Δ would $= 0$, and we might save ourselves all further trouble, and pronounce the dead escapement perfect, or capable of being made perfect, so far as the impulse is concerned. But it seems impossible to make $\gamma-\beta$ much less than 30′, and in fact it is seldom made so little. And it will not do to say that as 30′ only $=$ ·00085, that still leaves Δ very small, and so the clock must go very well; for it must be remembered, first that Δ only means the difference of time of a single vibration out of the whole number T in a day; and T is 86400 for a seconds pendulum; and further, that Δ is not after all the error of the clock between one day and another, but only the difference between the time of a pendulum swinging freely, and one kept going (or in mathematical language *disturbed*) by a clock escapement; and therefore we shall have to go one step farther and find the variation of Δ itself before we can know anything about the going of the clock.

since Δ cannot be made $= 0$. But before we do that it will be convenient to examine the value of it as it stands.

Let h be the daily fall of the clock weight Wg. The drop of the tooth at each beat, or the space through which the moving force Pg acts, ought to be nearly = the thickness of the pallet $= p\,(\beta+\gamma)\,tan\,\delta$; and this $\times$ T (the number of beats in the day) $\times$ Pg would = Wgh, but for the loss in the friction of the train and the slight difference between the actual drop of the tooth and its theoretical drop, which is the thickness of the pallet. For the present purpose it is of no consequence whether W is a little more or less, and therefore we may neglect this difference and consider $\mathrm{TP}p\,tan\,\delta = \dfrac{Wh}{\beta+\gamma}$; and therefore the excess of time of the clock pendulum over the free pendulum in the day, or

$$\Delta T = \frac{Wh}{Ml\pi a^2}\cdot\frac{\sqrt{a^2-\beta^2}-\sqrt{a^2-\gamma^2}}{\beta+\gamma}.$$

This is by no means a pleasant expression to deal with in a general way; but it is not difficult to draw the necessary conclusions from it, by assuming some particular values of the different quantities, in accordance with what they usually have in clocks. Although the error of the clock is not represented by ΔT, but by the variations of it, still if we can make ΔT very small, the variations of it in the same escapement will be smaller still; although it might happen, and in another kind of escapement does happen, that the variations are the least when ΔT is at a maximum. But there is no fluctuation of that kind here; and before going any farther we may observe at once the

advantage of a long and heavy pendulum, seeing that Ml is always fixed in the denominator of the expression for the rate of the clock due to the escapement. Moreover it is a fact that a long and heavy pendulum requires very little (if any) more force Wh to drive it than a short and light one; the reason of which is that the chief impediment to the motion of the pendulum is the resistance of the air, and the resistance to the surface does not increase in anything like the same proportion as the weight, if the bob is of a good shape. Therefore Wh in the numerator need not be materially increased for a very great increase of Ml in the denominator, which is directly equivalent to a very great increase in the accuracy of the clock; and you will see that the same is true in the other escapements.

The next point to consider is the length of the arc of impulse $\gamma+\beta$. As we have already seen that $\gamma-\beta$ ought to be made as small as possible, but cannot be made less than about 30′, let us take that difference as fixed, and see whether the whole angle of impulse $\gamma-\beta$ ought to be large or small compared with a. For simplicity of calculation, let us try the effect of making a, γ, and β in the proportions of 8, 7, 5, and 8, 5, 3, and 8, 4, 2, keeping $\gamma-\beta$ constant, you observe. Substituting those values then in the above formula for ΔT, you will find that it comes out in the proportions of 20, 14, and 13 in the three cases respectively. In other words, it is better *not* to make γ nearly $= a$, or the impulse to last nearly to the end of the arc; and it is satisfactory to know that this agrees with the conclusion which old Mr. Dent came to from observation, though it is contrary to the

practice of most other clockmakers, who seem to prefer that sleepy looking kind of escapement in which the second-hand moves very slowly and the 'excursion' of the pendulum beyond the impulse is very little. He altered the transit clock at Greenwich from a long to a short impulse accordingly with good effect.

Taking it then as proved that γ the angle of impulse after zero ought not to be nearly as large as a, we shall be able to simplify the above value of ΔT by assuming that $\frac{\gamma}{a}$ is so small that all higher powers of it than the square may be omitted. And then $(a^2-\beta^2)^{\frac{1}{2}}-(a^2-\gamma^2)^{\frac{1}{2}}$ may be expanded by the binomial theorem, and only two terms of each expansion need be taken, and the equation will assume the simple form

$$\Delta T = \frac{Wh\,(\gamma-\beta)}{2\,\pi\,Ml\,a^3}.$$

Mr. Airy concluded that the smaller $\gamma+\beta$ is, the better, as it appeared in the numerator of his expression for ΔT. The cause of the mistake was that he left the expression for the force unreduced into the terms involving the shape of the pallets, in which we saw that $\gamma+\beta$ was lying hid, ready to come out in the denominator of the fraction; and therefore, as it is also in the numerator, it disappears altogether, on the assumption that γ is moderately small, as it ought to be; and beyond that the above expression for ΔT gives no information as to the proper size of γ or the length of the impulse.

But then another consideration comes in. If you make the impulse very short, the pallet will slip away before the tooth has time to catch it; and the shorter the angle of impulse is the more of it is lost by the

inertia of the wheel (which therefore ought to be light): in fact this is another reason, besides the necessity for leaving a little of the dead face for the tooth to fall upon, why the angle β at which the impulse really begins cannot help being sensibly less than the angle γ at which it ends. Therefore also there is no use in making the pallet corners sharp, for the tooth cannot follow the pallet immediately, and it had better slide off a slightly rounded corner than drop on to the impulse face with a kind of jump off a sharp corner. On the whole the result appears to be that the escape had better take place at something near 1°, and consequently the impulse should not begin later than 30′ before zero, assuming a the extreme arc to be 2°, which will make $\frac{\gamma-\beta}{2\pi} = \frac{1}{720}$, and therefore $\Delta T \doteq \frac{Wh}{720\, Ml\, a^3}$.

The value of $\frac{Wh}{Ml}$ varies very much according to the quality of the clock: in the best astronomical clocks it may be taken to be as little as $\frac{1}{30}$ to make the pendulum swing 2°. As the force which arrives at the pallets is now represented by W, we must treat it as variable together with the arc; and so, differentiating ΔT, we shall have

$$d\Delta T = \frac{1\text{ sec.}}{21600\, a^3}\left(\frac{dW}{W} - \frac{3\, da}{a}\right) = 1^{s}\cdot 2\left(\frac{dW}{W} - \frac{3\, da}{a}\right).$$

If there was any definite relation between the ratio of increase of the force and the arc, this would give a very easy calculation for the variation of rate so far as the impulse is concerned. But there is not, as it depends on the state of the different parts of the clock. Sometimes it may happen that the pro-

portionate decrease of the arc from increased friction is just $\frac{1}{3}$ that of the force which arrives at the escapement, and then there will be no variation in the rate. Sometimes you may increase the clock-weight considerably without making much impression on the arc, if the pallets are dirty; and generally in an artificial experiment of that sort, except while the arc is smaller than 2°, $\frac{da}{a}$ is likely to be less than $\frac{dW}{3W}$, and then the clock will lose, even independently of the circular error which tends the same way, and which we know would be $10800\,a\,da$ if it were not in great measure corrected by the pendulum spring, though it is very difficult to say how much. On the other hand if you clean and oil the pallets alone the arc is sure to increase, and yet the clock will generally gain, because the increase is chiefly due to the diminution of the dead friction, which (as I explained before) would diminish the time, independently of the term $-\frac{3da}{a}$ belonging to the effect of the impulse, which retards less on a long arc than a short one.

Half-dead Escapement. In order to counteract the disposition of dead escapement clocks to gain as the arc decreases under ordinary circumstances (which, you remember, is the opposite of what happens in the recoil escapement), Berthoud a celebrated French clockmaker invented the plan of making the dead faces not quite dead, but with a slight recoil, so as to get a sort of compromise between the effects of the two escapements. Large clocks, which are subject to great variation of train force, are distinctly better when so made than

with quite dead pallets. Moreover the variations of the arc are rather checked by the half-dead pallets. The largest variations of arc I ever saw in a good clock, were in one of Mr. Vulliamy's, who used to take particular pains to make his pin-wheel pallets quite dead by cutting them out of a turned cylinder of radius equal to their distance from the arbor. A very slight recoil, such as you can hardly see in the motion of the wheel, is enough. But the best authorities are of opinion that a purely dead escapement is better in astronomical clocks, where the friction and variations of force are much less than in turret clocks.

Loseby's isochronal spring. Another plan for isochronising the long and short arcs was invented by Mr. Loseby a chronometer maker in London, and exhibited in 1851. A large circular loop of very thin steel wire is set on a stud from the back of the clock case, say on the right side of the pendulum, so as to embrace the rod nearly half-way down, just catching it as it swings to the left side of the loop. The farther it swings of course the more it has to stretch the loop, and the resistance increases in a high ratio with the degree of elongation; and it seems that this can be adjusted so as to isochronise the pendulum in a dead escapement under great variations of the force of the train, or of the clock-weight. So at least the Astronomer Royal reported after trying some experiments of that kind on two clocks, one with the spring and the other without it. But when this report was sent to me as chairman of the horological jury, it at once occurred to me that such experiments proved nothing as to the effect of such a spring on an astronomical clock in its natural

state, in which the variations of the pallet friction are generally greater than those of the train and produce the opposite effect, as is evident from the second term of the equation at page 89, and then the spring would make it worse. I found that Mr. Dent had some tables of the rates of several clocks under different states of oil on the pallets, which perfectly agreed with the theory, and so did some observations of my own on church clocks. I wrote to this effect to Mr. Airy, who then made a different class of experiments, this time by artificial variations of the pallet friction, and he issued a fresh report in 1853 concluding that 'Mr. Loseby's invention was *not* perfectly successful.' I have never heard of it being adopted in any observatory clock, any more than half-dead pallets, notwithstanding the facility with which it can be added. At the same time I see no reason why it should not be applied to any clock which is always found, as a matter of fact, to gain regularly as the arc falls off, and *vicé versá*.

Construction of dead escapements. There is one more point in the theory of dead escapements which requires particular attention in the construction of the clock. You observe that a^3 appears in the denominator of the expression for the variation of impulse rate, and so it would in that belonging to the dead friction. That is, the three resisters of disturbance of the rate are the weight of the pendulum, its length, and the cube of its arc. But the arc in any given clock in its normal state of friction varies in some irregular way with the force of the train, *i.e.* the clock-weight and its fall; and an increase of the weight in any given ratio may or may not increase the arc in the cube

root of that ratio: but so long as the arc is small, its increase will most likely be a great deal more than that; and if so there is a clear advantage in increasing the weight; subject always to this memento, that the circular error also increases with the arc. I had for some time thought that the disposition of some clockmakers, including old Mr. Dent, to reduce the weight as much as possible, and so let down the arc as low as 1° 30′ or less, was a mistake for this reason; and I found lately that the present Mr. Dent had also been arriving at the same conclusion, and had increased the arc and the weight of some of his clocks with a sensible improvement of their rate. It seems that 2° is on the whole the best arc for a 1 sec. dead escapement pendulum: and large clocks seem to do better with even a larger arc, up to about 2° 30′. Moreover the variation of the force itself is likely to be less in proportion if the force is amply sufficient to drive the train.

Whatever increases the arc without increasing the weight is obviously an important gain to the steadiness of rate; and the principal things which do that are diminution of friction and inertia of the train, and steadiness of suspension of the pendulum. I cannot give a better proof of how much the arc depends on that, than the effect of hanging the Westminster pendulum on its proper cock, which is a large mass of cast iron built into the wall, right through it; which increased the arc full 45′ over what it had been in Mr. Dent's factory, where it was hung on what seemed a perfectly firm support, on a strong timber frame built up from the ground. Even smaller pendulums generally increase their arc from about 2° in the factory to 2° 30′

as soon as they are properly fixed to a good wall on stone corbels or iron beams. This shows the extreme badness of the common way of fixing large clocks on a stool or timber frame set upon a wooden floor in a tower, and common clocks by a single nail through a thin back of the case.

The friction is of course only to be diminished by proper shaping of all the acting surfaces and making them of the best metals for working together. Brass wheels and steel pinions, and also brass teeth and steel pallets seem to be the best in small clocks, although there are other cases where steel and steel act better together, as in the horizontal watch escapement. In large clocks cast iron wheels and pinions suit each other better and wear less than any thing else, as has long been known by the great machine makers, though scarcely any clock-makers choose to believe it, and of course refuse to try, being what they call 'practical men,' who understand by the word *experience* the constant use of one thing or one way of doing it and absolute ignorance of any other. Mr. Vulliamy used to think steel scapewheel teeth or pins better than brass ones, and they have been occasionally used by other people, but I think are now generally disused. In the best clocks the pallets have jewels, generally sapphires, let in for the teeth to act upon, and it is quite ascertained that brass teeth suit them the best. The only large clock that I know of with jewelled pallets is that of the Royal Exchange, and it appears that some others of Mr. Dent's clocks go equally well with steel pallets, and the pinwheel escapement (which I shall describe presently), both having the same contrivance

for equalising the force, which was afterwards substituted at the Exchange for the original one on the French system, as I shall explain afterwards.

When the pallets are steel it is scarcely necessary to say that they ought to be as hard and as smooth as possible; especially the former, for, if they are not smooth at first the teeth will make them so in time, but soft ones will never get hard. They are hardened like files, by being heated red hot and cooled suddenly, and not tempered at all. The sharp hollow corners, which are considered by ignorant people a sign of fine work, are apt to crack in hardening, and as such a corner is always a weak place besides, they ought not to be so cut out; and the same remark applies to every hollow corner in every part of a machine, unless something else has to fit into it. Probably it is best to heat the pallets in lead melted red hot, and cool them in oil, which is now adopted for some larger steel things, as I have seen pallets twisted in the ordinary mode of hardening. The same may be said of pivots and pinions, except that they are tempered and not left quite hard.

Aluminium bronze. The alloy of copper and aluminium, to which this name is given, seems to me very superior to either brass or gunmetal for many horological purposes. It is stronger, much more elastic, smoother, far less liable to tarnish (*i.e.* to decay); and for small articles, such as the scapewheels of clocks, and all the wheels of chronometers and watches, the excess of the cost over brass would be insignificant. It solders well with either common 'silver solder,' or another with less silver in it. The pieces I have, both wire and sheet, were made by

Messrs. Johnson and Matthey of 79 Hatton Garden, who analysed the bit of Mr. Mears's unhomogeneous great bell for me.

It is important to keep the upper wheels in the train, and particularly the scapewheel, as light as possible. It is a well-known and well-founded rule that every blow you hear in the working of a machine indicates some loss of force, and wearing out of surfaces, and that the machine would be better without it—unless it is a hammer; and the heavier the blow is, of course the worse it is. In clock escapements a sudden stop and a blow of some amount is inevitable; but there is no reason why it should be increased by making the scapewheel three or four times the necessary size and weight, and the drop of the teeth more than is necessary to clear the pallets. I have already mentioned also that the greater the inertia of the scapewheel, the longer it is in effectively catching the pallet, although you cannot see the interval. This was one of the defects of Mr. Vulliamy's clocks, which were in other respects considerably in advance of the general work of his time, until Mr. Dent's improvements began. I have seen a visible cavity worn in the pallets by one of his large scapewheels in ten years, and the arc thereby reduced by nearly a degree. It was all the worse too, because the drop took place far above the corner of the pallets, the mistake of which I have already pointed out. I improved the going of that clock by altering it in that respect.

The scapewheel in the plan which he and the London Company of Clockmakers proposed for the Westminster clock would have come down upon the

pallets with a thump of 7lbs, increased by the momentum of the wheel itself; and the scape-wheel in a new clock in Shandon church at Cork, of which I have seen a drawing, is actually a foot in diameter, whereas that of the Royal Exchange, for a 2 sec. pendulum of $3\frac{1}{2}$ cwt. is only 5 inches and does not weigh half a pound. There are some clocks too, made by an engineer at Manchester, from which I have seen a scape-wheel removed, which strongly reminded me of a saying of old Mr. Dent's, that when engineers take to making clocks they always forget that they are not driven by a steam engine. Clockmakers, at any rate, ought to remember that the going part of a clock is a machine which has nothing to do but to overcome its own friction. Mr. Bloxam calculated that a pendulum of 15lbs does not require half as much force to keep it going as the balance of a marine chronometer: all the excess of force in the clock is spent in overcoming the inertia of the train, having to start it afresh from rest, remember, after every beat.

I may observe here that the rims of wheels (in which most of the inertia lies), and indeed the whole wheel, may be made materially lighter with 5 spokes than with 4. Sometimes, in the most expensive clocks, they are made with 6; but 5 spokes leave very little more than $\frac{1}{6}$ of the rim open, on account of their own thickness, as you will see in p. 102; and they seem to me quite close enough for clock-wheels; and of course every unnecessary spoke adds unnecessary work and expense: that number is used throughout the Westminster clock and many others now. Here too, as in the pallets, and indeed in every possible place, the

modern workman who is taught to think 'high finish' the perfection of work, or in other words to display as much finger work and as little head work as possible, files or 'crosses out' the corners as sharp as possible, instead of leaving them rounded a little, which would make the wheel stronger with no appreciable increase of weight. I believe it would be a very good rule that a sharp hollow corner ought never to be allowed anywhere, unless something has to fit into it, as it always makes a weak place, in which, if anywhere, things crack in casting, fly in hardening, or break in working, and moreover is so easy to do, that as a proof of good workmanship it is contemptible, even if it were not really bad besides.

Length of pallets. A French clock-maker in the Exhibition of 1851 had an apparatus for illustrating the superiority of moderately short pallets over long ones. It does not require much apparatus to prove that; for assuming the scape-wheel to be of any given size, it is evident that the farther the pallets are from their arbor the longer is the run of the teeth upon them, and the more friction there is affecting the pendulum. The usual proportion seems to be to make the distance of the pallets from their centre = the wheel's diameter (generally $1\frac{7}{8}$ inches in regulators), and embracing $10\frac{1}{2}$ teeth, *i.e.* from one dead face to the other. This seems to me rather an unnecessary length, and I should prefer $9\frac{1}{2}$, or half a tooth under instead of over one third of the number in the wheel.

I have seen clockmakers not used to dead escapements very much puzzled how to make and adjust them, and I have seen also some elaborate and con-

flicting calculations and drawings in French and English treatises about the arrangement of the pallets; which is really one of the simplest things in the world if you only bear in mind that the friction will be least and will vary least if the direction of the teeth is perpendicular to the dead faces of the pallets. Suppose that $9\frac{1}{2}$ teeth are to be embraced; then mark off that space on the circumference: the simplest way to do it is to lay the wheel itself on paper and mark its centre and the space of the $9\frac{1}{2}$ teeth at their circumference. Draw the radii to those points, and two straight lines perpendicular to those radii at their ends; and where these lines cross is the proper place for the centre of the pallet arbor, and the centre from which the dead faces are to be struck: unless you mean them to be half dead; in which case the theoretical centre for the right or down pallet should be taken a little nearer the centre of the wheel, in the line of centres, and that of the left or up pallet, a little more farther off. If you call the radius of the wheel r, and p the distance of each dead face from the centre of the pallet arbor, then (assuming that the wheel has 30 teeth and $9\frac{1}{2}$ embraced) $p = r \tan 57^\circ = 1{\cdot}54\, r$, and the distance of centres $d = \dfrac{r}{\cos 57^\circ} = 1{\cdot}84\, r$. Of course the principle of construction is the same, if you choose (as is usually done) to embrace 10 teeth instead of 9, and in that case $p = r \tan 63^\circ = 1{\cdot}96\, r$, which is practically $=$ the diameter of the wheel, and $d = 2{\cdot}23\, r$.

The slope of the pallets may be adjusted by trial. Fix an index to them of any convenient length, and put them and the wheel on centres at the proper

distance on a plate or board, and mark degrees for the index to point to: the length of 2° is ·035 × the length of the index, or ¼ inch for an index of 7 inches. Open the pallets till there is an interval of 2° between two successive escapes, and that fixes their points; then file the slopes back till the teeth just fall above the corners. The pallets should be just as thick as there is room for, which will be rather less than half the space between the teeth.

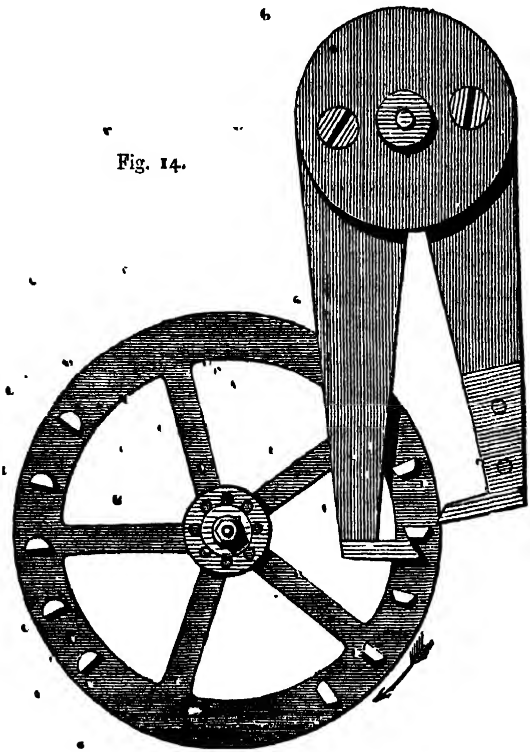
Adjustment of beat. Most people seem to know that the beats of a clock ought to sound equal in time, but also to have a very erroneous notion that this depends on the clock being set on a perfectly level surface, or standing vertically; whereas that has nothing at all to do with it, unless the crutch has been so adjusted that the pallets do escape at equal angles when the clock case stands level. Of course they ought to be so adjusted, because a clock looks better standing straight than crooked. In the best clocks the crutch is made adjustable by screws called beat-screws, which are set in various places according to the fancy of the maker. In common ones it is simply bent by hand till the beats sound equal. Mr. Dent makes the fork pins in turret-clock escapements to open with a spring, to prevent the teeth being damaged in case they should be caught by the escaping corner of the pallets when the clock is put back, or the pendulum set going, without the clock being wound up. Each 'prong' of the fork must have a separate spring, both set against a stop between them. The crutch and everything attached to the pallets ought to be kept as light as possible, because they are in fact a pendulum,

moving on pivots instead of a spring and therefore with much more friction than the real pendulum. But a long crutch is better than a short one, because less angular motion and force is lost in the looseness or 'shake,' which, as I explained at p. 73, must be left between the fork and the pendulum. The proper way to try whether a clock is in beat is to let the pendulum swing only just far enough for the escape, and then you will easily hear if the beats are unequal.

Pin-wheel escapement. There is a very convenient form of the dead escapement for large clocks, which goes by this name. It is said to have been invented by Lepaute in 1755, but also by Whitehurst of Derby. The teeth are pins of brass wire set in the face of the wheel, and the upper half of each cylinder cut off, as it could not act and would only waste room in the drop. But I introduced the plan of cutting off a small slice of the under or acting side also, as shown in fig. 14 (next page), because unless that is done, you must either have the wheel very large, or the pins very thin, or long pallets, or a large angle of impulse, which are all objectionable. The advantages of this escapement are, that it does not require so much accuracy of construction as the other, and less is lost in the drop, and therefore you can get many more pins than teeth to act in a wheel of given size, which often saves one wheel in the clock. If a pin gets damaged it is easily replaced, whereas if a tooth is damaged the wheel is ruined. The blow on both pallets being downwards, the action is more steady than it sometimes is in the other. The pallets are best made with their cross section rather convex, and also half dead. The

scape-wheel of Mr. Dent's large clock at King's Cross, by which the Great Exhibition time was kept, after vainly attempting to rely on some others about which

Fig. 14.



grand announcements were made beforehand, is only 4 inches wide, with 40 pins, so as to turn in 2 m. with a $1\frac{1}{2}$-sec. pendulum, and the distance of the lower pallet from their centre is about $3\frac{1}{2}$ inches. The lower pallet should be the inner one, and the higher the one outside

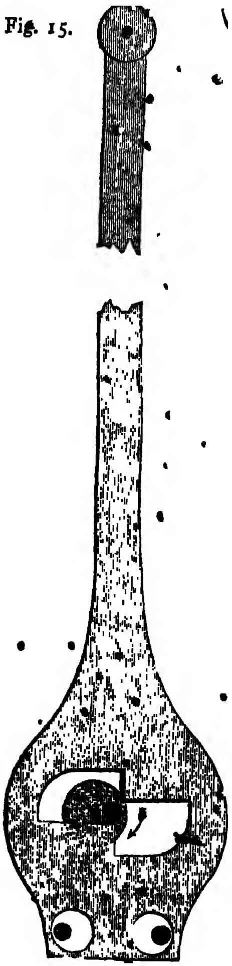
the wheel, because this makes the action of the teeth on both of them more direct. They are often made the other way, and it never occurred to me that it was wrong till I was struck with the oblique action in drawing one of that construction lately.

Pin Pallets. The best small French clocks that come here have an escapement which at first sight may be confounded with the pin-wheel escapement, but is really quite different. The scape-wheel is like a common dead scape-wheel, and it is set (merely for show) in front of the dial; but the pallets are made of semi-cylindrical ruby pins; the effect of which is that the dead part of the action is not on the points of the teeth but on their faces, and it is apparently half-dead. The impulse is the same as on common jewelled pallets, only with the faces round instead of flat.

Single-pin escapement. This, like many other new inventions, turns out to be an old one, both in England and France. But it was re-invented in an improved form by Mr. C. Macdowall, a London watchmaker, who is or claims to be the inventor of that very useful instrument the spiral drill; though that also turned up in the Great Exhibition, in wood from India. The scape-wheel (fig. 15, next page) is a very small disc with a single pin made of a ruby, like the pallets just now described. The disc turns half round for every beat of the pendulum, and gives the impulse on the upright faces of the pallet, and the horizontal faces are the dead ones. The action is smooth and easy, and it has the advantage of giving the principal part of the impulse directly across the line of centres, and it is very easy to make. It acts very well in watches also, as I

can testify from having worn one for some time which was made for Mr. Dent in Switzerland, he having bought the patent. But it has the disadvantage of requiring two more wheels in the train, which seems to overbalance the advantages, both in expense and in force required to drive the train. The pallet piece itself forms the crutch for the pendulum, the scape-disc being set behind the clock frame.

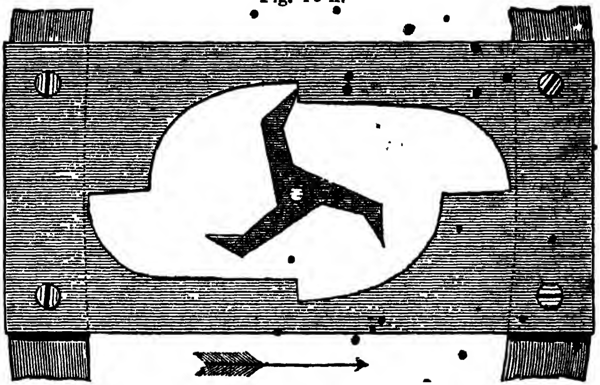
Fig. 15.



Three-legged dead escapement. It occurred to me in 1851 that all the best or most direct part of the impulse in the single-pin escapement might be kept, the more oblique part got rid of, and one of the extra wheels saved, by using three pins or teeth instead of one; and the result was this escapement, (for clocks only, not watches) in which the upper tooth is shown in the act of giving the impulse. Fig. 16 A is a *full-sized* view of the escapement which drove the Westminster pendulum of 6 cwt. for half a year, until it was superseded by another modification of it invented for the purpose of equalising the force of the impulse. That scape-wheel was of

steel and weighed only $\frac{1}{6}$ of an ounce or 73 grains, and the clock weight required for it with a common turret clock movement was only 18lbs. falling 6 feet a day, and less than a quarter of what a dead escapement had

Fig. 16 A.

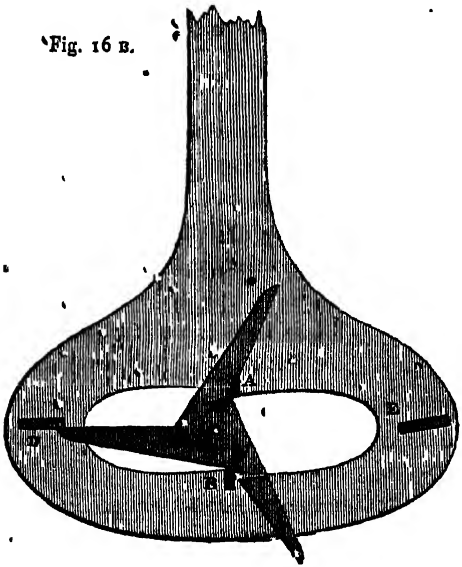


required; and considering that more force is lost by the inertia of such a train than in small clocks, we may say that the fraction $\frac{Wh}{Ml}$ was less than a third of its usual amount for the best astronomical pendulums swinging the same arc. I found also that it was possible to isochronise the long and short arcs—at least for such variations as actually occurred, by making the stopping or horizontal faces half-dead, as they are drawn here. The distance of the scape-wheel from the pallet arbor should be about 24 times the radius of the wheel, to make it escape at 1°, allowing a little for clearance.

The friction might be still more reduced and the adjustment of the pallets made easier by making the escapement with long stopping teeth, as in fig. 16 B.

It would also give room for a longer swing of the pendulum, which can not safely be made above 2° in the other form, or the stopping faces will reach the scape-wheel arbor. An escapement of this kind clearly reduces the pallet friction to the smallest amount possible in any dead escapement. It is however not

Fig. 16 B.



free from the variations of force in the train. Constancy of force is only to be got by an entirely different class of escapements, or by the addition of a train remontoire, of which I shall speak hereafter under Turret Clocks.

Detached escapement. There have been various contrivances for clock escapements on the chronometer principle of leaving the pendulum free or detached from

the scape-wheel except at the time of receiving the impulse and of unlocking the wheel. There is an old French one described in Rees's Cyclopædia, and Mr. Airy invented another, of which two or three specimens were made; but they seem to have had more inconveniences than advantages, especially when the cost is taken into account. In all escapements of this class the pendulum receives the impulse at only one of the two vibrations; which however is of no consequence; and as a whole tooth-space instead of half a one passes at each impulse beat, the scape-wheel turns in the same time as usual, supposing the number of teeth to be the same. There is therefore nothing new in the principle of the escapement I am now going to propose, though I think there is in its arrangement, and in the amount of friction which it saves.

First there need be no pallet arbor, and no crutch or fork, as there is nothing in the form of pallets except the single piece I, which is a bit of hard steel screwed to the plate P P, which may be part of the pendulum

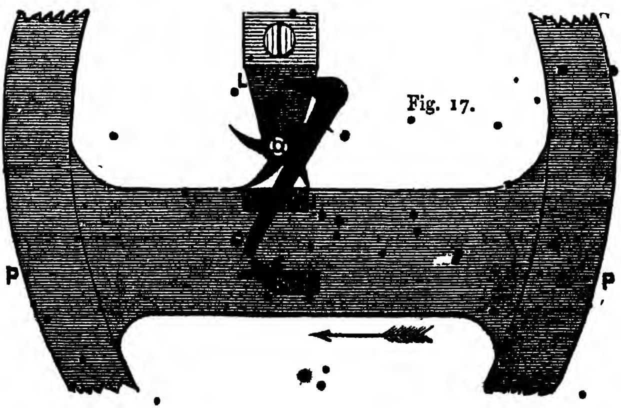


Fig. 17.

itself. It is cut out wide enough in this figure to allow an arc of full 3°. The scape-wheel may have either 5 or 6 teeth; if six, the depth of action would be so small as to require very delicate work, except on a large scale, and so perhaps 5 is the best number, and it is a very convenient one for the train. The scape-wheel should be in the middle plane of vibration of the pendulum, and therefore the plate P P must be a little behind the middle. The locking and unlocking is done by the lever Q L, which is just now at the moment of unlocking by the pendulum, which is going to the left and has not reached zero, but is at that angle which we called $-\beta$ in the common dead escapement.

You see how the unlocking is done by the lever and the little click C on the pallet plate, and the mode of giving the impulse is equally evident. Before the impulse is completed the click will have cleared the lever, which will have resumed its place and be ready to stop the next tooth. When the pendulum returns to the right the click will be merely pushed aside by the end of the lever without offering any sensible opposition to the motion of the pendulum; and when it comes again to the left the unlocking will begin at some such angle as $-(\beta + \delta)$ which must of course be something less than a or the whole swing of the pendulum from zero. The reason for the position and form of lever Q L is obvious, viz. to enable it to be pushed aside by the click and to return immediately. The impulse piece I, which may be jewelled if you like, can be adjusted by the screws by which it is fixed to the pendulum, and the click pivot or the pin which supports it may also be adjustable.

The distance of the scape-wheel from the top of the pendulum may be about 24 times the radius of the wheel, as in the three-legs, which will enable the impulse to last through 2° of the pendulum, allowing a little for clearance. In regulators this distance makes the scape-wheel come in a convenient position at the bottom of the frame, putting the seconds dial below the centre of the great dial instead of above it, as is done in the gravity escapement clock described afterwards. The pendulum hangs at the usual height. Fig. 17 would be the view of the clock from behind: but the impulse piece and locking lever may be put on the other side of the plate P P, to be visible from the front of the clock, through a large hole in the frame plates, and in the dial also if you like.

Another advantage of this kind of escapement is, that you may make the impulse begin and end at any angles you like (within moderate limits) before and after zero. We found that the reason why the common dead escapement, and any double-beat dead escapement loses under an increase of arc and force, is that the length of impulse before zero cannot be made as great as that after zero; and if this could be reversed, or the angle β be made greater than γ, the escapement could be made to accelerate the rate while it increases the arc, and consequently to counteract the circular error. In a single-beat escapement this can be done; and as there is no dead friction and scarcely any impulse friction in this escapement, there is no other source of error but the usual inequality of the impulse, which may thus be made in some measure to correct itself. And if a train remontoire is

added to make the force constant, as I shall explain hereafter, I am inclined to think this escapement would be superior to any other, so far as I can judge, without trial.

REMONTOIRE OR GRAVITY ESCAPEMENTS.

These are not to be confounded with the thing called a train remontoire, which I alluded to just now but shall not explain till we come to turret clocks, as it belongs only to them. A gravity or remontoire escapement is one in which the impulse is not given to the pendulum directly by the clock-train and weight, but by some other small weight lifted up, or a small spring bent up, always through the same distance, by the clock-train at every beat of the pendulum. And the great advantage of them is that the impulse is therefore constant; for the only consequence of a variation in the force of the clock is that the remontoire weights are lifted either faster or slower, which does not signify to the pendulum, as the lifting is always done when the pendulum is out of the way. If this can be managed with certainty, and without exposing the pendulum to some material variation of friction in the work of unlocking the escapement, which it must perform, its motion and therefore its time must be absolutely constant, since there is nothing to disturb it. It does not look a very difficult problem; and yet it puzzled the clockmakers to solve it in a satisfactory way for about a century, in consequence of certain small difficulties which nobody would guess until he had the opportunity of observing them in action; and after

all it was not done by the clockmakers, but by two lawyers, in different ways.

But first it may be asked, is the gravity escapement problem worth solving? Is not the dead escapement proved to be good enough both by experience and by mathematics? The answer is, that in science nothing is good enough when it can be improved upon: that both mathematics and experience prove that only by the most careful and delicate and therefore expensive work, and only on a small scale and with light weights, can dead escapement clocks be made to go so well as the best of them certainly do; and although we shall see that it is now possible, by the addition of an apparatus by no means complicated, to make even large and heavy dead escapement clocks go as well as astronomical ones, yet that apparatus involves not only some extra expense, but what is far more difficult to provide, some extra attention and intelligence in the people who have the care of it. We may however dispose of a great number of the almost innumerable contrivances for gravity escapements by the remark, that they require not less, but more delicacy of construction and careful handling afterwards than the finest dead escapement, even if they 'perform' any better, which scarcely any of them do.

Before we can appreciate the merits and the difficulties of this class of escapements, it is clearly necessary to understand the theory of them; which I shall be able to exhibit more briefly than that of the dead escapement, as some of the ground is common to them both, and especially that useful formula of Mr. Airy's for the variation of the time caused by any escapement, from which I shall start again. But it will

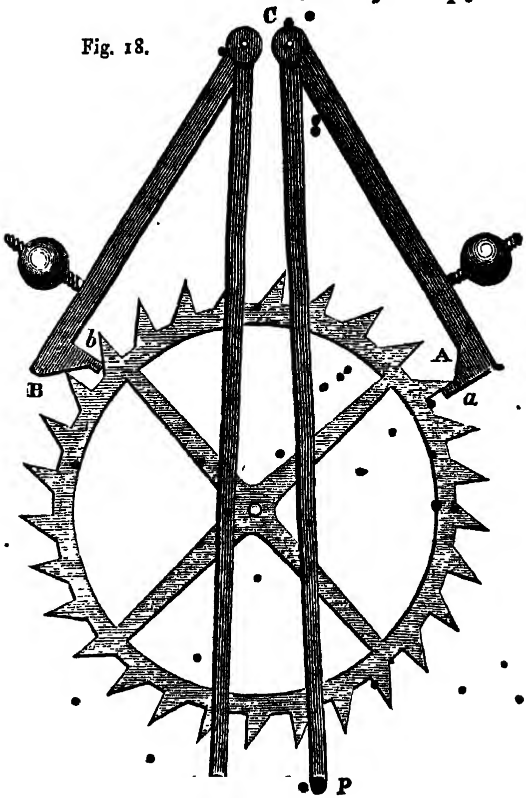
help our conception of the process if we first take some simple form of gravity escapement as an illustration of their principle; and it does not signify that that form was neither the first nor the best, on account of certain mechanical objections which we are not concerned with yet.

Mudge's gravity escapement. The pallets A C, B C, are no longer fixed on one arbor, but on two, as close to the bend of the pendulum spring as possible. The acting faces are so shaped and placed that whenever the wheel moves from B towards A, a tooth will lift one of them until it is stopped by the nib *a* or *b* at the end of each acting face. Here the pallet A has just been lifted and is holding the tooth that lifted it; as soon as the pendulum comes, moving to the right, it will evidently push that pallet out of the way by means of the fork-pin P, and so free the tooth, and the wheel will begin to turn, and the opposite tooth will immediately lift the pallet B till it likewise is stopped by *b*. The pendulum is all the time going on rising to the right and carries the right pallet with it as far as it likes to go; when it begins to fall the pallet falls with it, not only to the place where it was taken up, but to a lower place, corresponding to that of the left pallet in the picture; and the fall of the weight of the pallet from the place where it is taken up by the pendulum to the place where the pendulum leaves it, or the difference between its rise and fall with the pendulum, constitutes the impulse, and that difference is evidently constant, however far the pendulum may swing.

If the weight of the pallets were partly or wholly

counterbalanced, and they were fixed by springs instead of acting by their own weight on pivots, it could no longer be called a gravity escapement, but would have

Fig. 18.



the more general French name of a remontoire; but the principle would be the same, except that the force of the springs has a law of its own, and is more variable than that of gravity.

It is easy to shew that the effect of a gravity escapement is to make the pendulum go faster than a free pendulum, by exactly the same reasoning as was used to contrast the dead and the recoil escapements; or still more simply, by considering that the remontoire weights are in effect so much weight added to the pendulum far above its centre of oscillation, and therefore they accelerate it. But this tells us nothing about the variation of the rate, in case the arc increases or decreases a little under any change of friction; and we shall see presently that a very curious result comes out with respect to this, which it is impossible to arrive at except by calculation.

To do this we must find out again what that quantity called ψ, in Mr. Airy's formula at p. 83, is for this escapement. Let the angle after zero at which the pendulum begins to lift the pallet be called γ, and the angle at which it leaves the other pallet which has been giving the impulse $\pm\beta$, according as that takes place after or before zero: so that, as in the dead escapement, the angle $\gamma + \beta$ is the angle of impulse, if the descending pallet is left after zero, which we shall see is the best arrangement. Let Pg be the weight of each pallet, and p the distance of its centre of gravity from its axis at C, and δ the angle which p makes with the pendulum when they are in contact. Ml^2 represents the moment of inertia of the pendulum as usual; strictly speaking we ought to add to it the moment of inertia of the pallets while they are in contact with the pendulum; but as that makes no difference in the nature of the result, and in the best escapements one pallet or the other is always in contact, we may either consider that

as included in Ml^2 or neglect it altogether. Then the equation of motion will be

$$\frac{d^2\theta}{dt^2} = -\frac{g \sin\theta}{l} - \frac{Ppg \sin(\delta+\theta)}{Ml^2}.$$

And as we may put θ for $\sin\theta$, and 1 for $\cos\theta$,

$$\frac{d^2\theta}{dt^2} = -\frac{g\theta}{l}\left(1+\frac{Pp}{M}\right) - \frac{Ppg \sin\delta}{Ml^2}.$$

This is exactly of the same form as we had in the dead escapement at p. 84; only here the term involving θ, which always indicates isochronism, has its coefficient increased; which shows that the pendulum will regularly go faster than if its own gravity alone acted upon it, exactly as it is accelerated by those small regulating weights which I described at p. 65. The other term constitutes the disturbing force ϕ, from which we are to learn what will be the disturbance of the isochronism if the arc varies a little; and this result will also be of the same form as before, except that the limits of ϕ are different, as it does not act now through the middle of the arc only, but from $-a$ to β and from γ to a; and even if β should be identical with γ, the action is not continuous, for the falling pallet pushes the pendulum from $-a$ to β, but the pendulum lifts the pallet from γ up to a. Therefore the result of the integration will be (putting Wh for the sum of $Pp \sin\delta$ for the whole day):

$$\Delta T = -\frac{Wh\left(\sqrt{a^2-\gamma^2}+\sqrt{a^2-\beta^2}\right)}{Ml\pi a^2(\gamma+\beta)};$$

which differs from the dead escapement formula only in the signs; but we shall see that that produces another very important difference. First however we may

remark that if β is — (that is, if the falling pallet is left before zero), or even if it is smaller than γ (and it cannot be larger with safety to the locking), Δ T is increased, and so will all its variations when there are any. Therefore let us assume that β is as large as it can be, *i.e.* that one pallet is taken up just when the other is left, or $\beta = \gamma$; and then the formula becomes much more simple:

$$\Delta T = - \frac{Wh}{Ml\,\pi\,a^2} \sqrt{\frac{a^2}{\gamma^2} - 1}$$

We must differentiate this, as before, to see what the variation of rate will be; but this time we need not consider W or the force of the impulse variable, because we know it is not—if the escapement is what it pretends to be. Then

$$d\Delta T = \frac{Wh\,da}{Ml\,\pi\,a^3} \cdot \frac{\frac{a^2}{\gamma^2} - 2}{\sqrt{\frac{a^2}{\gamma^2} - 1}}.$$

From which this remarkable result appears,—that if the weight of the pallets is so adjusted that the pendulum swings through an arc $a = \gamma\sqrt{2}$, the rate will not vary at all, even when the arc does, except what may be due to the circular error. Unfortunately they both have the same sign, and therefore the escapement cannot be made to correct the circular error. But there happens to be a mechanical difficulty in making γ as large as $\frac{a}{\sqrt{2}}$ or ·71 a, which would be 85′ if $a = 2°$; and moreover Mr. Bloxam came to the conclusion, as stated in his papers, that from other causes, especially

the variation of density of the air, it is better to make γ considerably smaller than $\cdot 71\,a$. Let us see then what the variation of rate from the escapement will be for some such value of γ even as far as $\frac{a}{4}$ from the theoretical value.

In the Westminster clock I know by trial that $\frac{Wh}{Ml}$ at the escapement is not more than $\frac{1}{80}$; taking it at that, and a at 2° 40′, as it is, or perhaps a little more, and $\gamma = \frac{a}{4}$, you will see, if you take the trouble to make the calculation, that the clock will only gain ½ a second a day for a decrease of arc of 10′, which is much larger than is likely to happen, besides what is due to circular error so far as it is uncorrected by the spring.

In those escapements where the falling pallet is left before zero, the expression for the variation of rate would be

$$d\Delta T = \frac{Wh\,da}{Ml\,\pi\,a^3(\gamma-\beta)}\left\{\frac{a^2-2\gamma^2}{\sqrt{a^2-\gamma^2}}+\frac{a^2-2\beta^2}{\sqrt{a^2-\beta^2}}\right\}$$

in which you observe $\gamma - \beta$ instead of $\gamma + \beta$ is in the denominator, and therefore the fraction is much larger than in the other form of the escapement. Theoretically indeed this might also be made $= 0$ by making the three angles satisfy this condition,

$$\sqrt{a^2-\gamma^2}\,\sqrt{a^2-\beta^2} = \frac{a^2}{2}.$$

Thus $\gamma = 90'$ and $\beta = 78'$ would be right for $a = 2°$; but these small differences would be even more inconvenient mechanically, than $\gamma = 85'$ in the other case. That construction therefore is decidedly the

worst, notwithstanding the tempting appearance of the pendulum being left free through a great part of its arc; a fact which would probably never have been known with certainty without this kind of investigation, as the errors would have been sure to be attributed to any but the right cause.

Resistance of air. Mr. Bloxam says in a note to his first paper, that 'although it has been repeatedly '*proved* in works on dynamics' (and in a special paper by Mr. Bayley in the *Philosophical Transactions*) 'that 'the resistance of the air does not alter the time of 'vibration, this is only true on the supposition that it 'is the same in the ascent and the descent;' whereas the current produced in the descent prevents the pendulum from being retarded in the ascent as much as if the air had been at rest. Mr. Bloxam had no doubt that increased density retards the pendulum; as indeed it must, because it practically diminishes the pendulum's specific gravity. He says some persons have estimated the gain as high as ¼ sec. a day for a rise of 1 inch of the barometer, but he does not consider that ascertained. No doubt the resistance of the air helps also to diminish the circular error, which Mr. Bloxam and others have always found to be much less than its theoretical value. Reid also mentions, at page 139 of his book, a curious fact bearing on this. He says he cut a hole in the side of the case of a gravity escapement clock, which increased its arc from 1° 22′ to 1° 37′, and at the same time made it gain 42 sec. a day, and a larger hole increased the arc 12′ more, and I suppose the rate. Therefore the diminished resistance, from the pendulum being able to drive the air before it through

the hole, much more than counteracted both the circular error and the escapement error, making the clock gain this great amount instead of losing a little under the increased arc. Moreover such an enormous variation of rate as this shows that the motion of the air in the clock-case may affect the rate materially. But I must add that I have twice tried the experiment myself in a still stronger way, by taking off the clock-case altogether from my own gravity escapement clock, and I could not observe any increase of arc at all—certainly not of 5′, nor any alteration of rate. The arc was however nearly 1° larger than in Reid's clock before he cut the holes; and this is another proof of the unsteadiness of very small arcs.

Mudge's gravity escapement. Probably no one would foresee, without experiment, that the simple form of escapement in p. 113 would fail. Several of the most elaborate French turret clocks in the Exhibition of 1851 were on that plan, and people were very much surprised when I showed them that you could make all those clocks increase their arc visibly and speedily by increasing the clock-weight, which is directly contrary to the fundamental principle of a gravity escapement. This form of the escapement was invented by Mudge, a celebrated watchmaker whom I shall have to mention again, and it had long been known here that it would not answer, on account of its liability to *trip*, or to have the pallets jerked out so far by the motion of the wheel that the nib fails to catch the lifting tooth, and so three or four teeth run past and the time is altogether lost. The only way of avoiding this liability is to use a very highly finished train with

high numbered pinions to keep the force uniform, and then to make that force only just enough to raise the pallets; but that is inconsistent with the clock being able to work anything but a small dial, and if it is not kept very clean and the oil fresh, it will be sure to stop. In short the clock becomes too expensive and delicate, and requires too much attention to be tolerated in common use.

Cumming's escapement. But even if all these risks were got over, there is still another radical defect in all such escapements, which does not appear to have been ever noticed before I pointed it out with reference to those clocks in the Exhibition. The force may easily be enough to raise the pallets a little too high, without jerking them over the tooth altogether, and then the pressure on the nib is quite enough to keep them there, and so the pallet is taken up by the pendulum at some angle greater than the proper one γ; and as it falls down with the pendulum to a constant place, the impulse lasts longer than it ought, and of course the arc is increased. I gave the name of *approximate tripping* to this defect, and any escapement which is liable to it is evidently worth nothing. It seems capable of happening even where the impulse or sloped portion of the pallet is put on one arm and the nib on a separate one which is not lifted at all by the wheel, but only by the pendulum, as in *Cumming's escapement*, which was invented very nearly a century ago, and for a time was thought to answer well. I suppose this is in consequence of the force with which the tooth strikes the stop pallet, sometimes throwing it a little out of its place, unless it is

undercut or given a slight recoil the wrong way; and that is objectionable too, because it resists the unlocking, and does not always resist with the same force.

Hardy's escapement. One of the objections to Cumming's escapement was the friction of no less than 8 pivots of the 4 arms which had to move with the pendulum in the course of each vibration. Hardy avoided this by setting the arms on springs instead of pivots; but that introduced another and probably a worse evil, because the stiffness of the springs varies with the temperature, which of course disturbs the rate of the pendulum. That escapement was consequently removed from the transit clock at Greenwich many years ago and a dead one substituted. Nevertheless there are some very good rates of three Hardy's clocks published in *Pearson's Astronomy*. The Cambridge transit clock is his.

Kater's escapement. The late Captain Kater, who paid great attention to the theory of pendulums, invented a gravity escapement, which is very fully described in the 130th vol. of *Philosophical Transactions*, on the principle of making the weight of the descending pallet unlock the scapewheel by falling upon an anchor like a pair of dead escapement pallets without the impulse faces. He supposed that as the inertia of the anchor would stop the pallet for a moment, the pendulum would leave it there, and so be itself free from the friction of unlocking. But here again it was found that the force of the wheel was apt to displace the anchor unless its pallets were undercut, and then the resistance was sometimes too great for the gravity pallets to overcome unless they were too heavy for the pendulum;

and after many attempts to make it go, that escapement also was taken out of the only clock to which I know of it being applied, and came into the hands of Mr. Bloxam, who showed me it. The failure of it is described in his paper before mentioned.

Gowland's escapement, which was in the Exhibition of 1851, was on the same principle as to the unlocking, except that he had not even pallets for the inpulse, but a pair of small weights, which hung on long arms or spikes projecting horizontally from the locking pallets, except when they were lifted off by similar arms projecting from the pendulum. This prevented the friction of any pallet pivots affecting the pendulum. The locking pallets were of Mudge's form, and were prevented from being driven too quickly and tripping, by paddles descending from them into a pot of oil—not a very elegant contrivance certainly, and requiring a good deal of extra force in the train. I heard no more of it after the Exhibition, at which I was not surprised.

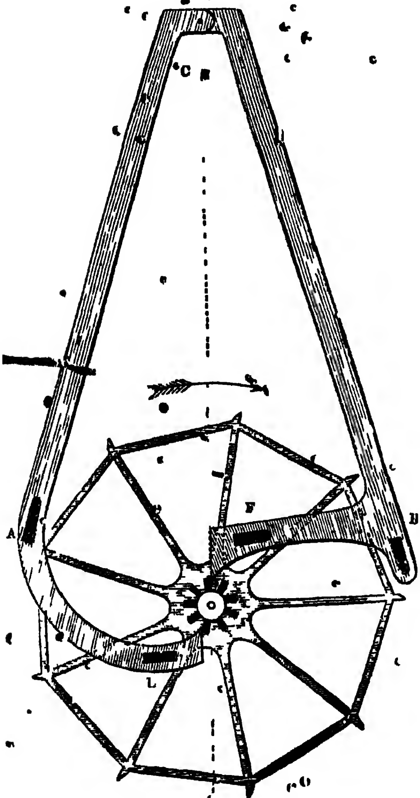
M. Gannery of Paris had an escapement there also, on the same principle as to the small weights, which were hung by strings from the pallet arms and received into cups on the pendulum arms, or *vice versâ*. But instead of the oil-pot, he made the scapewheel of the usual size with only 9 teeth of very slow rise and a nib at the end, which therefore lifted the pallets slowly and seemed to obviate the tendency to trip, so far as I could judge by merely looking at it. I should think however that the rigidity of the strings would be quite enough to affect the pendulum, and the friction in lifting was considerable. Moreover I doubt whether the stopping of the unlocking weight in any of this

class of gravity escapements is decisive enough to make the difference of the angles of lift and of drop quite constant; and if it is not the escapement fails. Of that escapement also I heard no more; and the French members of the jury evidently thought very little of it. Nevertheless the scapewheel with 9 teeth instead of 30, which reduces the pressure of the stops in that proportion, was a great advance in the right direction, though not absolutely new, because the same thing had been done much better some years before in

Bloxam's escapement. This is so superior to the others that it deserves a more particular description. This drawing (next page) of the full size in Mr. Bloxam's own clock, is copied (with a little alteration for distinctness of exhibition) from his account of it in the Astronomical Society's Transactions of 1853. The pallets are lifted alternately by the small wheel or pinion with 9 teeth, and with scarcely any friction, as the action is only for a short distance across the line of centres. The stopping is done by the long teeth, and the pressure there is less than the lift in the proportion of the radii of the small and large wheels. The stops are A and B: E and F are the fork pins which embrace the pendulum. The pallets above at C are cranked, that their centres of motion may be identical with that of the pendulum; which is perhaps an unnecessary refinement, especially as the pendulum spring has no one centre of motion. The size of the wheel determines that of the pallets, on the same principle as I explained for the dead escapement at p. 99. If the radius of the wheel is .1 in. the length of each pallet down to the stop must be 2·8 in. Mr. Bloxam made the angle γ, at

which the pendulum leaves one pallet and takes up the other, only 20′ in his clock, and $b = 1°. 40′$, these being the proportions which he concluded were the best to counteract the effect of variations of density of the air.

Fig. 19.

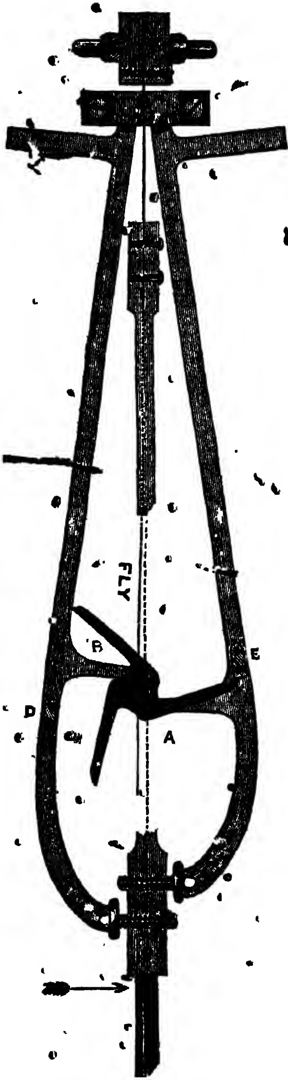


The only objections that I know of to this escapement are, that it is delicate and expensive to make, both in itself and in the rest of the clock, and that if a pallet got accidentally lifted the wheel would run with great velocity and probably break a tooth when the pallet stopped it again—an evil to which most of the previous escapements are equally liable, and it is a very serious one. Unless a gravity escapement will enable the clock to do with a coarse train, it is of no real use; at any rate it is quite certain

not to come into use; and Mr. Bloxam said that he considered a fine train essential. That in his own clock was the finest and had the highest numbered pinions (18) I ever saw. And therefore after all, that can only be regarded as a very perfect theoretical or scientific solution of the gravity-escapement problem, but hardly a practical one. Mr. Dent absolutely refused to adopt it in the Westminster clock, unless Mr. Airy and I should concur in requiring him to do so; which neither of us was disposed to do, although at that time we had not come to any conclusion as to the best escapement to adopt.

Three-legged gravity escapement. I have now to describe a gravity escapement which really has come into rather extensive use, especially in turret clocks. After the Westminster pendulum had been going for some months in 1852 with the three-legged dead escapement (p. 105), to which a train remontoire would have been added, it occurred to me that it might be converted into a gravity one with advantage, and that the two standing difficulties of gravity escapements, viz. the disposition to run too fast and actually or approximately trip, might be got rid of by the old-fashioned and simple expedient of a fan-fly. It then assumed this form. The drawing over the page is a view of a regulator escapement, seen through the front of the clock, half the usual size, in which d the distance of centres of the wheel and pallets has generally been made from 5 to 6 inches. The lifting of the pallets is done by the 3 pins, near the centre, which should be so placed as to act through 60° across the line of centres, which has to correspond to the angle of the impulse 2γ of the pen-

Fig. 20.



dulum; and as chord 60° = radius, r the distance of the pins from the centre, must $= 2\gamma d =$ from $\cdot 02d$ to $\cdot 03d$ according to the size of γ and a; say $r = \frac{d}{40}$ as a mean.

The length of the locking teeth is arbitrary: in small clocks they have generally been made about an inch, and in turret-clocks nearly 2 in. with the distance of centres 9 in. The only limit to their length arises from this: the radius from the centre of the wheel to the stop E, which is struck upwards, must not make less than a right angle with that pallet, or it will not lock but push the pallet aside and trip. Then if the beats are to be equal, the down stop D must be as much below the centre of the wheel as E is above it, and if it is much below, the unlocking has a scraping action, which is objectionable. In setting out an escapement then, the first thing is to fix the place of the up stop, and mark the points

of the other teeth at 120° from that: draw the small pin-circle, and a vertical straight line at the distance $\frac{r}{2}$ from the vertical line through the scapewheel centre. The centres of two of the pins are on that line, which will make them 120° apart, and the third is of course to be 120° from them. The peculiar shape which I have given to the scapewheel is merely for the purpose of making it as light as possible. The points of the teeth, should not be very sharp, or they will wear holes in the stops.

The horizontal pieces projecting from the top of the pallets form the adjustment for the arc of the pendulum, which in this escapement even more than in the dead had better be over 2° rather than under. The mathematical formula for the variations of rate indicates this no less than experience, having a^3 (or the cube of the arc) in the denominator, while Wh in the numerator no longer represents the variable force of the clock train, as it does in the dead escapement, but is simply the equivalent for the constant weight and lift of the pallets by the clock during a whole day, and a slight increase of that weight increases the arc more than a similar increase of clock weight does in the dead escapement. I improved the going of a regulator of this kind materially by increasing the arc to 2° 15′; and in turret clocks it is generally made a little over 2° in the factory, which always increases to 2° 30′ or more when they come to be firmly fixed on stone corbels or cast iron beams in a clock tower.

The setting on of the fly requires a little notice. The fly itself must be quite loose on the arbor before the

friction spring is attached, for if it is tight at first it will wear loose and fail to act, and then the clock will trip · the friction must be got entirely from the spring. Two pieces, or even one piece of stiff watchspring bent in between the arbor and the hole in the middle of the fly, seems to be the best way of doing it in small clocks. In turret clocks with a large fly you may have two short stiff springs screwed on to the arms of the fly and acting either on the arbor or a small hard cylinder pinned to it. It is a mistake to cut the arbor small where the spring acts: it should rather be larger than the other part, especially when the fly is as large as 6 in. × 1½ in each arm, which is about the size for ordinary turret clocks. Regulators only require a very small fly, not above ⅞ in. square in each vane.

All gravity escapements require more clock weight than a dead escapement with the same kind of train; and this one requires more than usual, because the work has to be done by a scapewheel which turns ten times as fast as usual and has to turn the fly besides; and although theoretically it makes no difference in the force required, it does practically make more than anybody would imagine without trial, whether the same quantity of friction or resistance has to be overcome by a fast or a slow wheel in a train of any kind of machinery. In large clocks indeed, this difference is hardly apparent, because the force required by the escapement is very small compared with what is consumed in merely moving the train and the dial work; but in small ones the difference is much more striking, though it does not affect the pendulum at all. If it was worth while, it would be easy to do the lifting by

a common small recoil escapement wheel with 30 teeth put on the arbor of the 1 min. wheel prolonged through the back plate of the clock, which wheel would lie very conveniently between the pallets and might lift them by its teeth acting obliquely on a steel pin in each pallet. In that case the lifting pieces A and B of the pallets in fig. 20 would be omitted, as well as the pins in the scapewheel. I should mention that the usual position of the train is inverted in regulators with this escapement, the large wheels being put at the top and the scapewheel centre an inch from the bottom of the frame. A large hole is somtimes cut in the frame plates and the dial to enable the action of the escapement to be observed.

Fig. 20 also shows how the beat is usually adjusted in small clocks. In large ones it is generally done by setting the fork pins on eccentric nuts. Care should be taken to adjust it so that the pendulum takes up one pallet as nearly as possible when it leaves the other, besides of course making the beats sound equal. Steel pins are found to do the best for steel faces, and also steel teeth on steel stops; but brass pins and teeth if the pallets and stops are jewelled, of which the only advantage here is that they require less oiling, as the friction of lifting does not affect the pendulum. Here also the *aluminium bronze* mentioned at page 95 will probably be found better than brass.

Approximate tripping is impossible with this escapement, for another reason, besides the fly; for if you lift the pallets by hand into that state, they will fall down again, notwithstanding almost any pressure which you can produce on the stops by the train, even when the

stops are sloped away a little to make the unlocking easier and the friction insensible: which is exactly the contrary of the undercutting which was required in the old forms of gravity escapement. The fly gives you complete command over actual tripping, and it should always be made so large that you cannot make the escapement trip by twice the usual clock weight. This also proves that this escapement really supersedes the necessity for a fine train of high numbered wheels, which no other has pretended to do. Even Mr. Dent was for some time unwilling to believe that a coarse train would really answer as well as a fine one, and so he tried the experiment; and the clock with the fine train went no better, but as it happened, rather worse than several of the coarse ones.

It must nevertheless be understood that this escapement was invented for turret clocks and not for astronomical ones, and I do not propound it as superior or even equal to a dead escapement for astronomical clocks of good construction throughout. But it can be made a good deal cheaper than the best dead escapement clocks on account of its not requiring a fine train. One of these clocks has been in use for several years at the Cambridge observatory. In the great Northumberland equatorial telescope room, a clock with a very loud beat was required. This cannot be got in a dead escapement without sacrificing some of its time-keeping properties, by giving the teeth a long drop and putting on a heavy weight. Clocks of that kind are sometimes put on for the job, and are thence called 'journeyman clocks,' being set by a good one before you begin observing, and they go well enough for a

short time. But a clock with this gravity escapement can be made with a loud beat, and even to strike a small bell every minute if you like, without affecting its going at all, by merely increasing the weight as far as you safely can without the risk of tripping, and making the scapewheel rather thicker than usual. The Cambridge clock is found loud enough by an observer who is rather deaf, and the rate has several times been reported to me as quite good enough for the purpose. It may be worth mentioning that Professor Challis found it once gain 3 seconds on the day of a heavy thunderstorm. The first of these clocks that was made, a very rough experimental one, was tried at Greenwich, and the Astronomer Royal was so well satisfied with it after trying what he called 'some malicious experiments' on it, that he approved of Mr. Dent using it in the Westminster clock, although he had himself written strongly against gravity escapements in general, and did not like this on those general grounds when he first saw it.

The first clock of this kind, after that experimental one, was made by Mr. Dent for the Cathedral at Fredericton: indeed the escapement was invented for it, as the Bishop told me they must have a clock that would stand the cold of 40° below zero, which would stop most clocks of the common construction, or at any rate affect their going seriously. Fortunately there is a scientific clock-maker there named White, who has taken great interest in it, and shown considerable judgment in making various little alterations which were naturally required in a machine of a new construction, not even fixed by the maker; and I have

heard from him very satisfactory reports of its performance, even 'while the oil has been frozen as hard as tallow.' One of the first put up in England was at the Manchester Infirmary, where it works four 9 ft. illuminated dials, all in the clock-room, which is very hot in summer days, being a thin dome; and the gas must make the heat vary considerably every day and night in cold weather.* Reports of the going of that clock have been published from time to time in the Manchester papers, from which it appears that it only varied 14 seconds, and that by a nearly constant rate, in the year ending July 1859, and the rate was equally constant in the year before. Without mentioning other cases where the information is less precise, though to the same effect, I was struck with one from a gentleman who has an observatory of his own, and who writes that he had had the escapement of a turret clock altered from a dead one with a wooden pendulum (which the London makers consider the perfection of the art of large-clock-making) to this with a compensated pendulum, and that it had '*reduced the variation of the clock from minutes to seconds.*'

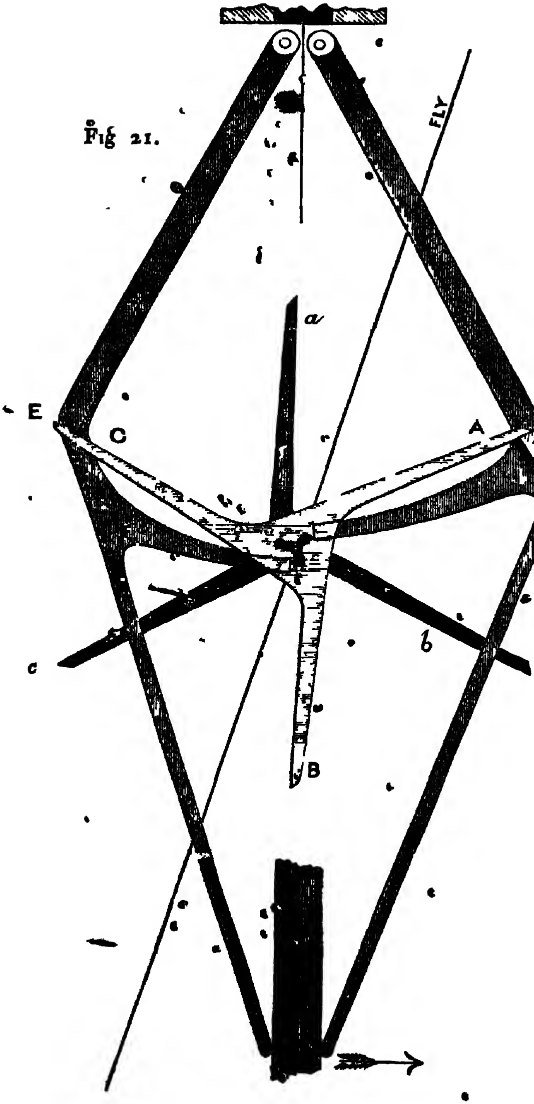
There have been different opinions whether the place of action of the beat-pins should be high up or low down on the pendulum, *i.e.* above or below the

* Some persons however, who have these clocks, think that they require more compensation of the pendulum. I should like this to be observed carefully by those who have the means of doing so, as I have only heard of it with any certainty in two cases. If so, it is very easy to give a greater length of compensation tubes. I do not observe it in the rate of the Cambridge clock, which is subject to very large variations of temperature, as observatory clocks always are. It is visibly affected by changes of the barometer, as other clocks are; see p. 118.

scapewheel. I am convinced that it is better to have the action lower down than it can be if the beat-pins are above the scapewheel. In some of the experiments there was a sensible variation even of the arc, and of course of the rate, when the beat-pins were put higher up; and I cannot but think that in any case where the contrary has appeared, the advantage has been entirely due to the diminished weight of the pallets, which we shall see can be got in another way. I am not prepared to give any rule for the length of the pallets, but the rate was worse in the Westminster clock when they were 15 inches than 18, and worse in a clock with a $1\frac{1}{4}$ sec. pendulum at 6 inches than at 12. It is evident too that the shorter they are, the greater angular variation there will be for any absolute variation in their position from the shake of pivots or any other cause; and so a long crutch is better than a short one in a dead escapement, provided it is not too heavy, as they very often are.

Double three-legged scapewheel. In turret clocks with heavy dial work, and therefore a large force on the scapewheel generally, it is desirable to reduce the pressure on the stops by making the teeth 3 or 4 inches long; but that, as I explained just now, would either make the down stop come too low, or the beats very unequal. This however may be avoided by the simple expedient of two locking-wheels, with one set of lifting-pins between them (fig. 21, next page). They are set wide enough apart for the pallets to lie between them, and you must take care to have sufficient clearance throughout to make sure of the pallets falling with the pendulum, clear of all other contact; one pallet, say D, has its stop in front for the

Fig 21.



wheel A B C to act upon, and the E stop points backwards, and only the wheel *a b c* acts upon it. (You must not suppose that the tooth C in the drawing is in contact with the stop E, for they are in different planes.) Both stops can now be placed at the points where radii of the scapewheel make right angles with the pallets. If *d*, the distance of the centres, is a little less than $2a$ (a being the length of the teeth), the points of the two scapewheels will lie exactly in a hexagon—not that that is of any consequence, except that it makes them rather easier to set: the reason why d is not exactly $= 2a$ in that case is, that the arbors of the pallets are necessarily separated a little, and therefore the theoretical centre is a little above the real one.

There are several advantages in this way of making the escapement. First, by making the teeth longer and the pallets shorter, you reduce the resistance to the pendulum from the pressure and friction of unlocking very materially; and little as it is in any form of this escapement, compared with the pressure on the pallets in a dead escapement, or in any of the old gravity escapements before Mr. Bloxam's, it is not insignificant; as you may see from this:—hardening and polishing or oiling the stops increases the swing of the pendulum sensibly. Another advantage of the double scapewheel is that it makes the stride of the pallets wider, and therefore their effective weight greater, or the actual weight required in them considerably less. This reduction of the weight and moment of inertia of the pallets, and their impact on the pendulum, and the friction on their pivots, is certainly of great value, besides there being an evident improvement in the

steadiness of the action. Hitherto this form of the escapement has only been used in very large clocks, such as Westminster and Leeds; but I am disposed to think it is worth while to adopt it in smaller ones, as the additional cost of the second scapewheel is insignificant; and as some compensation for that, it enables us to dispense with all the beat screw arrangements. For the long pieces from the stops to the pendulum need be no thicker than wires, and may actually be wires brazed on to the pallets; and as the adjustment for beat has never to be altered after it is once made right, it may be done just as well by bending these wires with a pair of pliers when the clock is first fixed as in any other way. I believe also that their elasticity would be an advantage, as it would diminish the blow on the pendulum at every beat.

I should think about 3 inches would be a good length for the teeth, and therefore nearly 6 inches for the distance of the centres, in a common turret clock, and half that size, or the size of fig. 21 (which is rather less), in a regulator. The lifting pins will have to be very near the centre, as their distance ought not to be more than $\frac{1}{10}$ the distance of the pallet arbors from the scapewheel. In small clocks, the best way will be to make the scapewheel arbor of six-pinion wire with every other tooth cut out, as shown in fig. 21. It should then be set so that the lifting face of the pallet may rest ~~flat~~ against the face of the lifting tooth at the beginning of the lift: in other words, the lifting is to begin at the line of centres, although when there is room enough for pins and a distinct arbor, it is better to begin 30° before the line of centres, as I said at

p. 125. As the pallets will be only half the length that they have usually been made in regulators, it will no longer be necessary to invert the train and put the scapewheel at the bottom instead of the top. The pallet arbors may be set in a pair of cocks rising above the top of a frame of the usual height. But if you prefer having the escapement at the bottom, in order to be able to see the action of it better (cutting a piece out of the dial and the bottom of the frames), there is no difficulty in it: the pallet arbors must be short, with one pivot in the back frame plate, or a piece screwed within it just behind the centre wheel, and the other in a cock as close to the pendulum as possible. It is obvious that the effect of the pressure and friction on the stops will be only one third of what it is with the pallets six times the length of the scapewheel teeth, as they have usually been in regulators with the single three-legged wheel.

Four-legged scapewheel. The same object can be effected, though not quite so completely, by a single wheel with 4 legs, but having 8 lifting pins, pointing alternately backwards and forwards. The pallets must be in different planes to suit them, with one stop in front and the other behind. In this escapement the length of the scapewheel teeth and pallets is not arbitrary as in the three-legs, but the proportions requisite are convenient enough. If you draw a four-legged wheel with one of the legs standing at the angle $22\frac{1}{2}°$ with the vertical or line of centres, another of them will be at the proper place for locking; and the pallet at right angles to it will make that same angle with the vertical. Calling the length of the teeth a, and d the distance of

the theoretical centre of the pallets (*i.e.* the point to which they converge, or where their arbor would be if it could be single, or where the pendulum spring bends), you will find that $d = 2{\cdot}6\,a$; and p the distance from the pallet centre to the stops $= 2{\cdot}4\,a$, whereas it is only $1{\cdot}73\,a$ in the double three-legged escapement with equidistant teeth; and the force of the train on the scape-wheel will of course be also one third more, as it turns in 8 seconds instead of 6; so that altogether the force required in the pendulum to unlock a four-legged wheel of given size is nearly double of that in fig. 21, though a good deal less than in fig. 20. You will see at once the reason why two sets of lifting pins are required for a wheel of any even number of teeth if you take the trouble to draw it; viz., that either the upper or the lower pallet can only be lifted by very oblique action if they are both lifted by the same set of pins.

I can say from observation that this four-legged escapement acts perfectly well, though not quite so steadily as the double three-legged in large clocks, where there is generally and ought to be a large amount of superfluous force, to make sure of driving the hands in all weathers. In regulators this is not so, and in them the four-legs would have the incidental advantage of avoiding the small pinion, only $\frac{1}{10}$ of the size of the minute wheel, which the three-legs involves, and which wastes a good deal of the force, as small pinions always do. A wheel and pinion of 60 and 8, or of 75 and 10, would be right for a four-legged scape-wheel in a regulator. The teeth might conveniently be $1\frac{1}{2}$ in. long, which will make the theoretical distance of centres $3{\cdot}9$ in., and the actual distance of the pallet arbors $3{\cdot}5$ in. above

the scape-wheel arbor. The distance of the lifting pins from the centre must of course be more than in the three-legs to produce the same lift: it should not exceed $\frac{1}{30}$ of the distance of centres, and probably will be better $= \frac{d}{36}$, or you may find it difficult to get the pallets light enough not to make the pendulum swing too far. The same remark applies to the double three-legs, because one of the objects of them both is to reduce the absolute weight of the pallets.

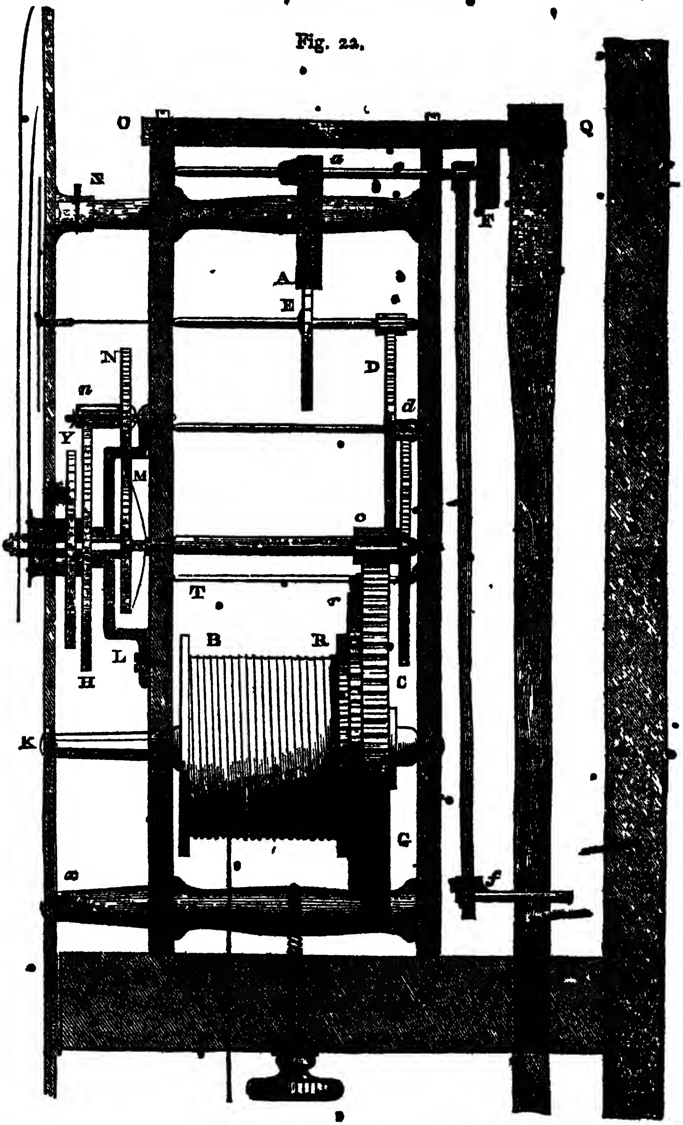
CONSTRUCTION OF THE GOING PART OF CLOCKS.

Fig. 22 shows the usual arrangement of the going part of a common regulator, or a house clock of superior character, except that the pendulum in a clock of that kind ought to be hung by a cock on the back of the case; but I have already given a drawing (fig. 8) showing that; so I show another mode of suspension here. In the common recoil escapement clocks the pendulum only weighs a pound or two, and is hung from a cock merely screwed to the back plate of the frame, which is a much weaker plan than this. The weight is not hung by the single line, but by a double line going through a pulley, sometimes in the weight itself, but more frequently hung to it by a hook. This prevents the string from untwisting, and enables you to do with a thinner string, and it requires a barrel of twice the diameter which a single string would, and that is worth something when the pivots of the barrel are as large as they usually are, of which I have spoken already at p. 82. But it must be remembered that every pulley in a machine, and

especially every moveable pulley, wastes power very sensibly by the friction and stiffness of the rope, especially when the moving power is at the slow end of the system of ropes. Theoretically it makes no difference whether a given weight with a given fall in a week is hung by one rope without any pulleys or by half a dozen; but practically you will find the weight has to be increased in a very high ratio for every additional pulley you add. You might soon reach a number at which no weight whatever would do the required work, but would all be wasted in overcoming the friction and stiffness of the ropes. This remark is chiefly important with reference to turret-clocks, since not one architect in a hundred ever consults a clock-maker before he plans either dial-holes or clock room or place for the weights to fall, and then people think it is the clockmaker's fault if the clock does not perform as well as if it had plenty of room for the weights to fall and other things to act properly.

The barrel is fixed to its arbor, of which the back end is a common pivot, but the front is carried through to the dial K and is squared for the key to take hold of it. The great wheel G rides loose on the arbor between the barrel and a collar shown just above G, and it is connected with the barrel by the ratchet and click, of which a front view and description has been already given at page 26. (There are in fact two ratchets R and s in fig. 22, but we need not inquire into the functions of the second at present: it will be explained with fig. 25.) The great wheel G drives the centre pinion *c*, which always turns in an hour, and its arbor goes through to the dial and carries the minute hand in

Fig. 22.



the way I will describe presently. The centre wheel C drives the second pinion *d*, on whose arbor is a wheel D which drives the scape-wheel E by its pinion *e*. In moderately good clocks the pinions have all generally 8 teeth or leaves, and the wheels in that case have 96, 64, and 60 teeth; if the scape-wheel turns in a minute as usual: in the best clocks the pinions are occasionally as high as 16; Mr. Bloxam's is the only one I ever saw with pinions of 18. Of the scape-wheel, pallets, and pendulum, I have said enough already. In dead and gravity escapement clocks, and sometimes in recoil escapements, the scape-wheel arbor comes through the dial and carries a seconds hand.

Short clocks with half second pendulums are best made with a scape-wheel of the usual number of 30 teeth, as either a large and heavy wheel, or teeth very closely set, are objectionable. In that case the scape-wheel will of course turn twice in a minute, and the product of the numbers of the teeth of the centre and second wheels must = 120 × 8 × 8 if the pinions are of 8, which is best satisfied by 96 and 80. In very inferior clocks the scape-wheel pinion is only 7, and then 84 and 80 teeth will do. The American clocks have lantern pinions (see fig. 47) in which 6 pins are as good as 8 or 9 common teeth, and therefore the centre and second wheels need only have 72 and 60 teeth for a half-seconds pendulum. It is not worth while to go on with the calculation for $\frac{3}{4}$-seconds pendulums or others, as the principle of it is perfectly obvious.

Dial work. If the minute hand were fixed rigidly to the centre arbor, the clock could never be altered; and therefore the way in which it is fixed and yet

alterable is this: there is a wheel M (in fig. 22) set on a hollow arbor or pipe which fits easily on the centre arbor, and has its own end squared for the hand to fit it. A small bent spring with a hole in the middle fits on the centre arbor, and the hole rests against a shoulder which is turned on the arbor just in front of the clock frame; the ends of the spring press against the back of the wheel M when it is pressed back, as it is after the hand is put on, and it is kept there by a collar and a small pin put through the end of the centre arbor.

And in this small matter there is room for a very common mistake: the hand is kept steady by the friction of this spring at one end and the collar at the other, and it will evidently be much steadier for the same amount of pressure if the spring fits the arbor tight, and so the friction is between the ends of the spring and the back of the wheel, than if it is loose on the arbor, simply on account of the difference of leverage at which the friction acts when you turn the hand with your own finger. In mere regulators without any striking part, this does not matter, because there is nothing to disturb the hand; but when the wheel M, or the equal wheel N which is driven by it, has to lift a lever every hour to discharge the striking part, it matters a great deal, because a great deal more friction is then required to hold it in its place against the pressure of the lever; and yet it seems to be the fashion in London to make the hole in the spring round instead of squaring it on to the arbor; which would take about ten minutes to do. The consequence is that a clock will sometimes take to losing unaccountably in this way, which I only first disco-

vered by seeing the minute hand gradually lag behind the seconds hand; and that defect can only be permanently cured by making the spring very much stiffer than it need be if it is put on properly, *i.e.* with a square instead of a round hole.

Over the minute-wheel M and its hollow arbor there is fixed a thing called the *bridge*, which is shown at M L (fig. 22), and has another pipe enclosing that of the wheel M but not touching it; and the hour-wheel H with another hollow arbor still larger rides upon the bridge pipe, and is driven by a pinion *n* of $\frac{1}{12}$ its own number of teeth, which is fixed to the wheel N of the same number as M. That wheel N is generally set upon a stud or a pin screwed into the front plate, but is better with pivots in the frame and a cock. The hour hand is set on the end of the hour-wheel socket either with a small screw or pins. The thing marked Y in front of the hour-wheel has nothing to do with the going part of the clock, but is the *snail* which regulates the number of hours struck by the striking part, as will be explained under that head.

The hour hand in astronomical clocks generally has a small circle to itself in the lower half of the dial, to prevent its hiding the seconds hand in the upper half, which it is important that an observer should always be able to see. Besides it moves with much less friction when so placed, as it then turns on a thin stud fixed on the front plate of the clock, instead of a very wide socket. It may either be driven by an intermediate wheel and pinion from the centre arbor, in order to make it go the right way round, or directly by the great wheel, which involves less friction and no incon-

venience except the perfectly insignificant one of having to move the hour hand separately from the minute hand when you want to alter the clock much, which cannot happen once a year in any good clock.

Dial. Two different ways of fixing the dial are shown in figure 22, and both of them different from the common one, in which four separate pillars are screwed permanently into the dial and the other ends go through the front clock plate and are pinned behind it, the main pillars of the clock itself being only long enough to connect the two plates, and having nothing to do with the dial. Either of the two plans in the figure seems to me to be better than this, though it is a matter of very little consequence. The dials of the best clocks are made of brass plates polished and silvered: the common ones are of sheet iron: the American and Dutch of wood. The hands are always of black steel in regulators, but in common clocks they are of brass gilt, which is a very bad colour on a white face, though very good on a black face. The same remark applies to watch faces. I never could understand how such an absurd thing as gold hands on white faces—and still worse on gilt faces, came into existence, especially as gold hands of that small size have not even the vulgar merit of being dearer than steel ones.

Winding keys are generally made too short in the stalk or leverage, which makes the clock harder to wind and tends to strain the arbor besides, as you may see from considering that if the stalk was very short indeed any force applied to it would be chiefly consumed in trying to bend the arbor. As there is absolutely no advantage in a short key, this is one of the many

instances of doing wrong for the pleasure of it, when it would be quite as easy to do right and the effect much more pleasant. All my seconds pendulum clock keys are 3 inches long or more: keys for small clocks may be 2½ in. The French spring clocks without fusees, in which the winding is very hard towards the end, have keys like a very large watch key or a piano-tuner, to prevent the strain upon the arbor. But this makes the winding a much longer operation and a very unpleasant one, as you have to stop at every half turn. Sometimes such keys are given with small English fusee clocks, for which there is no excuse. You should take care that the wood or ivory on the handle of a key is quite loose, or it increases the resistance materially.

Year clocks.—Clocks without striking parts are sometimes made to go a month, and occasionally even a year. For a month they only require one more wheel and pinion with a multiplier of 4, between the centre and great wheels. Year clocks require 3 wheels below the centre, and the pinions ought to be of 10, 10 and 12 at least, on account of the great weight required, which will have to be still greater if the pinions are of low numbers. Assuming the clock to go 380 days, and the barrel to have 16 turns as usual, the product of the 3 wheels must $= \frac{380.24.12.10.10}{16}$, for which 100, 90, and 76 will be the best numbers. This is far better than trying to do it with only two wheels of 192 and 190 (the lowest possible numbers), and pinions of 8, in which the friction will be very much greater. The best way is to have two barrels and great wheels acting on one long pinion of 12, with the

weight hung by the same string from both barrels by a pulley which only turns while you are winding up; and there must be a winding stop to each barrel.

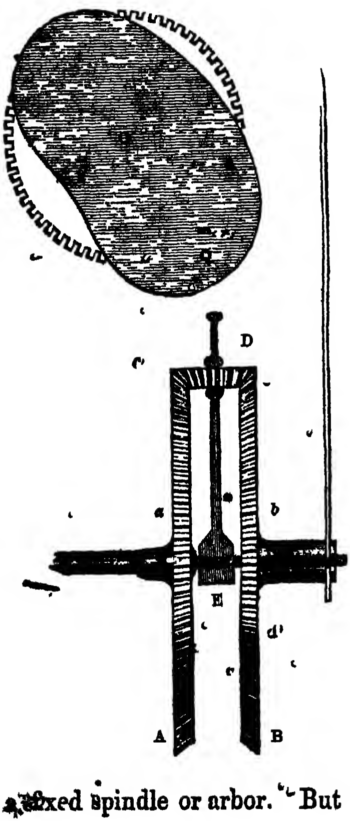
Clock cases are necessarily connected with the construction of the clock. The old tall case with a base as big as the top, standing on the floor instead of screwed to the wall, is sufficiently exploded to require no more to be said against it. The case need be no longer than is required for the pendulum, as the weights can have 3 lines, or smaller barrels, or larger great wheels, of which the last is the best. The weights themselves of course have to be half as heavy again as with the fall one half longer. The best case for a superior clock is one of which the front and sides take off together. There need be no door to the face, but only small brass or white metal shutters over winding holes in the plate glass front, which enables you to lock up the clock completely and leave anybody to wind it up. Ornamental case making I have nothing to do with, and it is not much of an exaggeration to say that the value of the inside of a clock generally varies inversely as the decoration of the outside.

Day of the month clocks. These are nearly obsolete, partly because people generally forgot to re-set them at the end of the short months, and also because the figures were too small to be seen except very near. They had a round plate with 31 divisions engraved on the front, which appeared through a hole in the main dial, and the edge of the plate was cut into 62 ratchet shaped teeth which were driven by a single tooth in the hour wheel, one every 12 hours, and kept steady by the pressure of a slight spring when the tooth

was not acting. I have seen some cheap clocks by a Mr. Taylor of Wolverhampton, with complete self-adjusting month-work, but they are all open to the same practical objection that the figures are too small to be seen across a room.

Equation of time clocks. A still more obsolete contrivance, but worth recording for the principle of its machinery, was that for making the hands of a clock show solar instead of mean time, at least in a rude and approximate way. A*a* in this figure is a bevelled wheel on the centre wheel arbor, which in this case is made to turn the wrong way round, and another equal bevelled wheel B*b* rides upon it, with a hollow spindle *b c* to which the minute-hand is fixed. Between these two is another small bevelled wheel of any size, which would merely reverse the motion, if it was set on a fixed spindle or arbor. But it is not, for it rides on

Fig. 23



the end of a bar or lever D E, which itself turns upon the centre arbor and has its end D beyond the wheel resting on a plate of the odd shape shown at Qq, which is fixed to the face of a wheel which turns in a year. Now if the lever D E, or the centre of the small wheel, is moved at any time in the same direction as the hand is going, it will evidently push it forward just twice as much as the lever itself is moved, and *vice versâ*. If then the equation plate Qq is on the right side of the clock-frame, the hand will go ahead of its mean motion whenever D drops below the mean radius of the plate from O the centre of the year wheel, and will fall behind mean time when the protuberant parts of the plate are uppermost. The plate then may be so shaped as to make the advance and retardation of the hand agree with the 'sun before clock' and 'sun after clock' of the equation of time.

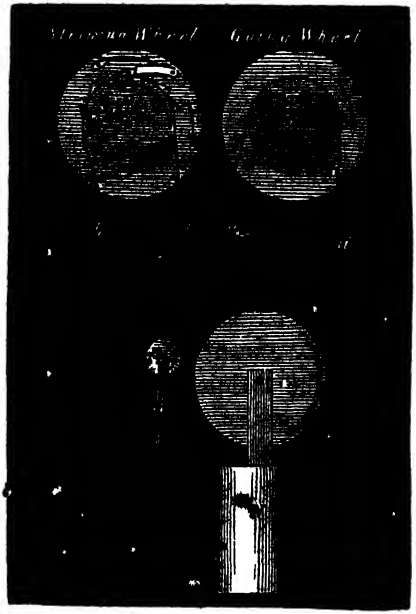
There are two other ways of giving a secondary motion of this kind; one, by substituting a common small wheel or pinion for the middle bevelled wheel, and putting it between Aa made as a common wheel, and Bb made as an *internal* wheel, *i.e.* with teeth inside its rim; but in that case you must remember that A and B will have different velocities, and therefore A must turn in less than the hour. The other method requires neither bevelled nor internal wheels, and is on the same principle as the one I shall describe more fully at fig. 39 under *train remontoires*.

Clocks for showing other celestial motions are mere curiosities, and are always getting out of order from their complication; so I shall not waste time in describing them, but go on to something more practical.

MAINTAINING POWERS OR GOING BARRELS.

Winding up a clock evidently takes the action of the weight off the great wheel, and so the clock movement stops for the time, though the pendulum goes on swinging. This of course will not do in a clock of any accuracy, whether a large or a small one, and as the same methods of keeping the clock going (or some of them) are applied to both, I shall describe them all together here.

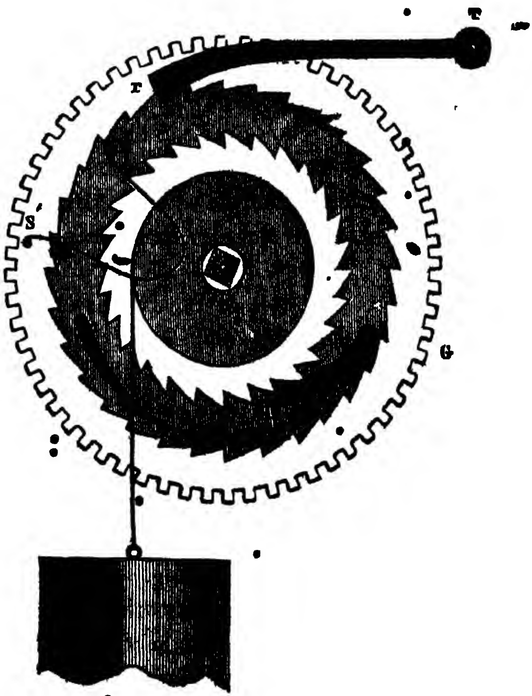
Fig. 24.



The oldest of all the plans is *Huygens's endless chain.* In this drawing P in the 'going wheel' is a pulley fixed to the great wheel of the going part, and having short spikes set in it, or roughened in some other way so as to prevent a rope or a chain hung over it from slipping. A similar pulley rides on another arbor *p*, which may be the arbor of the great wheel of the striking part, if the clock has one, and attached by a ratchet

and click to that wheel, or to the clock-frame if there is no striking part. The weights are hung as you see, the little weight being only big enough to keep the string in the pulleys. If you pull *b* the left hand of all the strings down, the ratchet pulley moves under the click, and the great weight is pulled up by *c*, without taking its pressure off the going wheel at all. This plan was generally used in the old 30 hour clocks, but went out with them, as the action of a chain or even a rope hung in that way is rough and uneven; and more-

Fig. 25 (for next page).



over the pulleys must be of only half the usual diameter for the same time of going.

Harrison's going barrel is the maintaining power used in all regulators now. The larger ratchet wheel *r* in fig. 25 is the one designated by the same letter in fig. 22; and the click is fixed to that wheel, which is connected with the great wheel by a spring S S′. While the clock is going the weight acts on the great wheel G through the spring; but as soon as you take off the weight by winding, the click T*r*, whose pivots are set in the frame, prevents the great ratchet from falling back, and so the spring still drives the great wheel during the time the clock takes to wind, especially as it need only just keep the escapement going, for the pendulum will take care of itself for that short time. The drop of the great click over the teeth of its ratchet may be heard every 10 minutes or so while the clock is going. Good watches have the same apparatus.

Bolt and shutter. Another contrivance, which is now used only in large clocks, is an arbor with a weighted lever at one end of it, with a click in the form of a spring bolt on another lever; when the weighted arm is lifted up the click takes into the teeth of some one of the train wheels, and the weight then keeps the clock going till it works itself out of gear in a few minutes and drops. The weighted lever is outside the clock and is made with a cap or shutter which shuts over the key-hole when it is down, to make sure of your lifting it before you begin winding. With the usual ingenuity for doing things wrong, this click is very often made not as a sliding bolt, but with a hinge, so that there is one position of the lever in which it jams

against the teeth and stops the clock for good, unless the winding man finds it out and releases it, which he probably will not. Sometimes too the click sticks, and sometimes it slips, even if made rightly. There is another defect besides in the common bolt and shutter, viz. that it may work itself down and rest upon the winder or key before the winding is done if the man is slow about it, and then it does no good and the clock stops for the time.

Improved bolt and shutter. To prevent these evils, and to simplify the construction, I introduced the plan of substituting for the 'bolt' a segment D (see fig. 41), of a small wheel suited to the teeth of the great wheel, and making the arbor C, which carries that and the shutter M, to pump in and out of gear, and the shutter not covering the key-hole, but made as a circular arc to the centre C, which all but touches the winder when it is on. The winder has a ring, the dotted circle near M in fig. 41, put round its end, which prevents it from being put on until you have lifted the shutter, and put it into gear with the great wheel, to hold it up. As you go on winding, the clock goes on and the shutter descends, now behind the ring, which secures your pulling it out of gear again when you take off the winder, and yet it will keep in action full 10 minutes if left to work itself out. Mr. Dent now generally uses this plan in his large clocks.

I shall describe hereafter another totally different plan for keeping a very large clock going when the winding takes a long time; but as the spring going barrel does very well for small clocks, and the improved bolt and shutter for any but a clock of quite unusual

size, I shall postpone that description till we come to the Westminster clock. For the same reason I need not repeat the description of Mr. Airy's going barrel, which was applied to the Exchange clock, but is so expensive that it is certain never to be used again. A full description of it was given by him in vol. 7 of the Cambridge Phil. Trans. The object of it was not only to keep the power always on the clock, but exactly the same power; for the power of the spring falls below that of the weight, and that of the bolt and shutter doubles it just at the times of putting it on and taking it off; but that is of no consequence, except in a revolving pendulum clock, for which the apparatus was invented; he has since simplified the construction, but it is still an expensive one, and the thing can be done at $\frac{1}{10}$ of the cost by the Westminster method without either loss or duplication of force.

Spring clocks. Hitherto we have supposed all clocks to be kept going by a weight. But many clocks have no weight and have a spring made of a long ribbon of steel coiled up in a barrel for their moving force. This construction however belongs so peculiarly to watches that I shall defer the description of it till we come to them. I will only mention here that the French clocks, like French and Swiss watches, generally have the great wheel fixed to the barrel, which of course makes the force on the train unequal. In that case the barrel arbor goes loose through the barrel ends and is fixed to the inner end of the spring, and has also a strong ratchet squared on to it, with a click on the clock frame, which holds it when you are not winding up. And a barrel of this kind is of itself a 'going-

barrel,' for it keeps the power on as much while you are winding as at other times—in fact rather more. English spring clocks always have a fusee with a chain, made as in the view of a chronometer movement at fig. 49, to equalise the force on the train.

I understand that this class of clocks are now sold more than any other, *i.e.*, spring and fusee clocks with half-second pendulums, either in cases made to stand on a bracket or to hang up against a wall. The American clocks have become so bad through the violent competition in them, that I am told not one is sold now where ten used to be. But the old-fashioned English long clock with a seconds pendulum has not regained its place, and no wonder, for a more ugly and clumsy and cumbrous piece of furniture was never contrived. A clock with an equally long and a better pendulum, and with weights instead of springs, and only two-thirds of the length, may be made for less money. I have no doubt that if any man with capital, time, and spirit, and real knowledge of what is essential and non-essential in clock-making, would establish a factory for making clocks, as Mr. Hobbs has for making locks, he might do it with the same success and advantage both to himself and the public, making a far better machine than either the American or French clocks, for less than the usual English price and more than the usual profit.

ELECTRICAL CLOCKS.

A self-winding or perpetual motion clock is a chimæra of the same order as 'the philosopher's stone,'

and even still more visionary; for I do not know that the transmutation of metals is *demonstrably* impossible, but perpetual motion is, so long as the present laws of nature remain.

And this is equally true whether the earth or a permanent magnet supplies the attraction which is to move the machine. For it can only move under the action of gravity by reason of the centre of gravity of the whole descending, however the action of it may be complicated or disguised; for the heavy parts must always preponderate over the light ones. Then a time must come when the centre of gravity has got as low as it can; and after that how is it to get up again? Clearly it never can by any action of its own, because that would require the light parts to pull up the heavy ones. Exactly the same reasoning applies to a permanent magnet; for when that part of the machine on which the magnet acts most strongly has got as near to it as possible, it is manifestly, and à fortiori, impossible for it to tear itself away again, as the force increases enormously as the parts get close to each other. There has lately been a paragraph travelling through the newspapers about a self-winding clock, which the editors evidently believe in, as they do in flying machines and other mechanical prodigies belonging to a different order of nature from that which subsists yet. Either the inventor has deceived himself, or his clock is a clever conjuring trick, like Robert Houdin's famous dial and hand without works, or he avails himself of the variation of some natural force, such as the expansion of air or mercury in different temperatures, which has been done long ago, and is as much a self-moving machine as a windmill is.

It would be easy enough to make a wind-winding clock if it was worth while.

What then is the difference between this and an electrical clock kept going by temporary magnets made and unmade by a galvanic battery? Simply that the clock can unmake those magnets by an insignificant exercise of force in breaking the continuity of the galvanic circuit, in which there is no attraction between the parts, as there is between the magnet and the iron. When the magnet is unmade, the piece which it attracted can fall back again, and so a reciprocating motion is got, which may be as perpetual as the duration of the elements of the battery, of which one must be used up exactly as if it were common fuel burnt, and force got out of it in that way.

Bain's clocks. The first plan for purely electrical clocks was Mr. Bain's, who made the pendulum receive its impulse from electricity; the bob being hollow and passing over two soft iron cylinders made alternately into magnets at each beat of the pendulum by its making contact with a small sliding piece. But this plan failed, and of the three pendulums which used to go in Mr. Bain's window in Bond Street while his shop existed, some one was generally stopping, or going so feebly that it was evidently going to stop very soon.

Shepherd's clocks are on a plan much more likely to answer. They have in fact an electrical gravity escapement, raising a pallet by a temporary magnet which acts on the pendulum when swinging in one direction, either lifted with it as far as the pendulum may go, or lifted on to a dead escapement pallet attached to the pendulum, which is probably the better plan.

The connection of the pendulum with the clock train, or any number of clock trains, is made by a pair of common recoil anchor pallets worked backwards and forwards by the magnets, which are made and unmade at every beat, as in Bain's clocks, and in the still earlier electrical dials of Professor Wheatstone, which were driven by electrical connection with some common clock. If you take the weight off a common clock and move the pallets backwards and forwards you will drive the train, but the wrong way; and therefore these electrical trains must have their scapewheel and pallets reversed, but in other respects they may be like a common clock train.

But Mr. Shepherd made another important alteration, by arranging his magnets so as to repel and attract alternately, instead of leaving the separation to be done by gravity. The bars or *armatures*, acted upon by the temporary magnets, are themselves permanent ones, in the form of two flat pieces of steel put across the pallet arbor with their north and south ends reversed, over the ends of two soft horseshoe temporary magnets. At one beat of the pendulum, say the left, connection is made with the — pole of a battery by a slight contact spring near the top, and the current sent accordingly through the wire which surrounds and magnetises the left horseshoe so as to attract the adjacent ends of the pallet magnets, and the right horseshoe the opposite way, to repel them; at the other beat the contact is made with the + pole of another battery and the current sent the other way round both magnets, and so their poles and their attraction and repulsion are reversed. The other wires of both batteries are soldered together and ultimately con-

nected with the pendulum cock after passing round the magnets.

The Time-balls at Greenwich and the Strand are let off by electrical connection with the Royal Observatory clock, thus:—the circuit is only complete when two contact springs are pressed together by a pin in the scapewheel, and another pair by the minute hand or centre wheel, and another by the hour wheel, all concurrently. The pin in the hour wheel (which turns in 12, or it may be in 24 hours) may be made to fix anywhere, so that you can alter the hour of discharge. The best way of making the contact in all cases seems to be by a platinum spring coming down upon a platinum point, because that keeps itself clear of dust: it seems also that a rubbing contact does not answer for electrical purposes, nor a wire or point dipping into a cup of mercury, though any one would probably expect otherwise of both of them. The discharge of the ball is done by a trigger with a long lever armature pulled by the magnet, when it is made by the completion of the electrical circuit in the way just described. The ball is a large wicker-work globe covered with canvass, on the top of a piston which slides in a slit in the pole, and falls into a bell-mouthed tube with a small air hole in its lower end, so that the air checks the sudden fall of the piston and yet lets it go down to the bottom. Notwithstanding the simplicity and the apparent infallibility of this arrangement, I am told by persons who have observed it regularly, that the Strand time-ball does fail sometimes—as every thing else does which depends on the certainty of electrical action, so far as I have been able to ascertain.

Jones's electrical corrector. I give this name to a plan which was invented a few years ago by Mr. R. L. Jones, the general manager of the Chester station, for keeping a number of even bad clocks right by electrical connection with one good one; and which has the great advantage of not requiring absolute certainty or continuity of action. If the pendulum of a common clock is made like Bain's pendulums, capable of being attracted at each beat by a temporary magnet made by an electrical current from a standard clock beating the same time as the other ought to beat, a very slight amount of magnetism is sufficient to keep the inferior clock in exact agreement with the standard one; and it will not signify if the magnet fails for several beats together, unless it fails until the error of time exceeds one beat of the pendulum, after which the magnet would make it worse until a full double vibration was lost or gained. It is true that these are not electrical clocks in the sense of having electricity for their moving force, and so dispensing with winding up; but that is of no consequence, for it only takes a few minutes even in a large clock, and anybody can wind up a clock when there is nothing else to be attended to, and therefore it is an operation which cannot be said to have any money value at all—except to be sure when it takes a man a whole day, as at Westminster. The first clock which was used as the standard one for this purpose at the Chester station was the small gravity escapement clock sent by Mr. Dent for trial by the Astronomer Royal. I hope this invention will not encourage the making of bad dependent clocks instead of good independent ones.

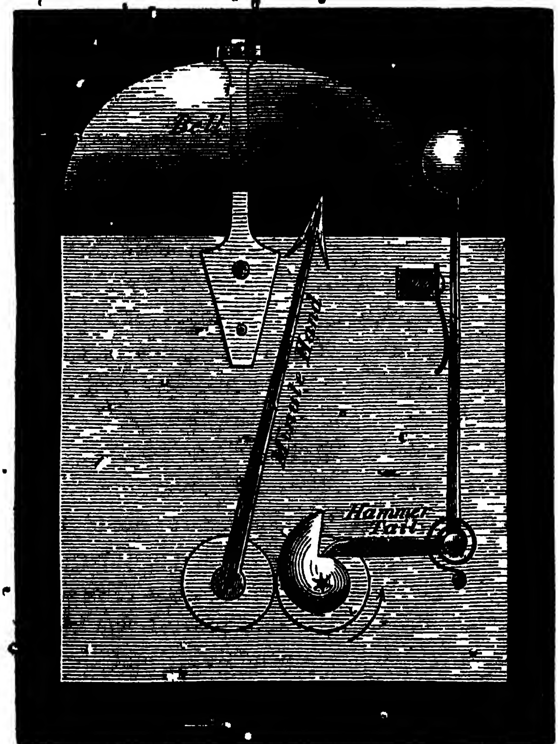
By this contrivance also the uncertainty of electrical discharge of a time-ball is got over. The ball on the Victoria Tower at the Collingwood Dock at Liverpool is let off by mere mechanical action from a strong clock below, which is kept right by electrical connexion on Mr. Jones's plan with the clock at the Observatory under the management of Mr. Hartnup; and so is the Town Hall clock.

STRIKING CLOCKS.

The simplest form of a striking clock is represented in fig. 26. It only strikes one at every hour, which is sometimes more agreeable than striking the full hour, especially where you can easily see at once what the hour is. It is very seldom that anybody has to count the striking of a clock except in the night. Striking one requires no striking part, or separate machinery to be wound up, the hammer being lifted by a snail (or sometimes, but worse, by a pin) on any wheel which turns in an hour, and dropped as the minute hand reaches the hour. It cannot be done however without affecting the friction of the clock, and therefore its rate, except with a gravity escapement or some equivalent contrivance to prevent the inequality of force from reaching the pendulum; and the remark which I made at page 143 about the importance of fitting the dial spring on to the centre arbor with a square instead of a round hole, applies still more strongly here, as the friction of that spring has to overcome the resistance of the hammer spring. The short spring against which the hammer shank falls is to prevent it from jarring on the bell, and this is necessary in

every case both in large and small clocks, unless some other contrivance is resorted to for the same purpose, such as I shall speak of under turret clocks. In common clocks this check is given in a simpler way, as

Fig. 26.



shown in fig. 27, where the square top of the stiff spring S butts against the square piece on the hammer shank, whose own elasticity lets the hammer strike the bell and then pulls it back again just out of contact.

A piece of vulcanised India rubber tied round the pillar also answers very well.

This is a front view of the common construction

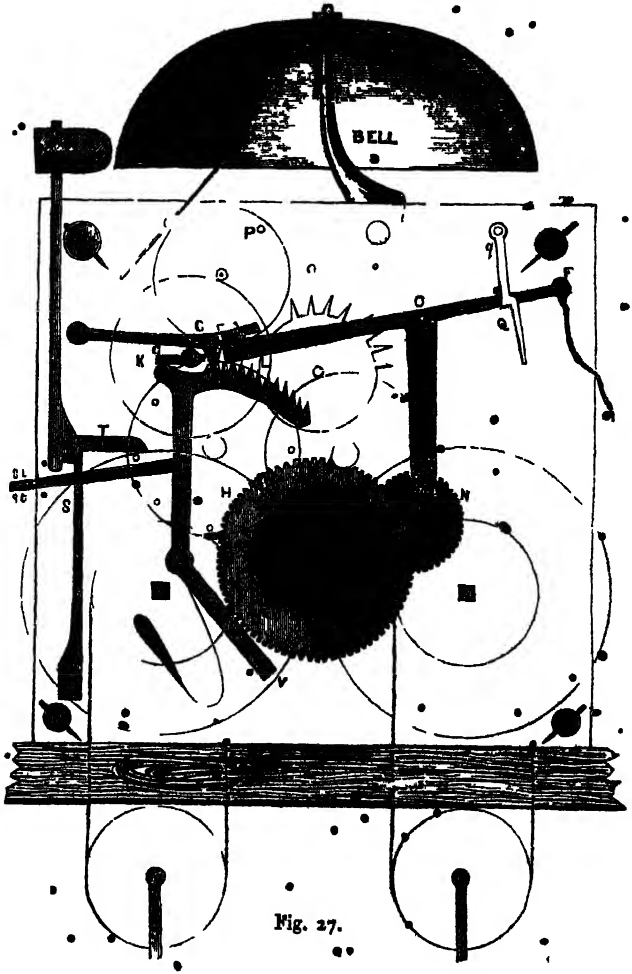


Fig. 27.

of an English striking clock; the foreign ones are different, as I will explain presently. The wheels shown only by circles (with a few of the scapewheel teeth) are within the frame; only those with teeth are outside, and they are indicated by the same letters as in fig. 22. The hammer tail is raised by 8 pins in the second wheel of the striking train, which corresponds to the centre wheel of the going train. The pinion of that wheel generally has 8 leaves, and is driven by the great wheel of 78, which therefore turns in 12 hours; not that that is at all material, and of course higher numbers would be better. The striking wheel drives the wheel above it once round for each blow, and that wheel drives a fourth, in which you see a pin P, six or any integral number of turns for one of the third wheel, and the fourth wheel drives a fly to moderate the velocity of the train and the time of striking.

The number of blows to be struck is regulated thus: the dial-wheel N has a pin on its face which raises the *lifting piece* L O N a little before the hour, just far enough for it to lift the long click C out of the teeth of the *rack* B K R V, which then falls back (helped by a spring at its tail) as far as its tail V can go by reason of the position of the snail Y on the hour-hand wheel; which has steps in it, one for each hour, so as to let the rack fall the distance of one of its own teeth for every hour the clock ought to strike. This fall of the rack makes the noise called *warning* a few minutes before the clock strikes. The reason why it cannot begin to strike yet is that the pin P cannot pass a stop which is turned inwards from the lifting piece, through a large hole in the frame, until that piece drops again, which it

does exactly at the hour by the advance of the pin in wheel N. Then the striking train is free, and that little piece K G, called the *gathering pallet*, which is squared on to the prolonged arbor of the third wheel, gathers up the teeth of the rack, one for each blow of the hammer; the click is lifted as each tooth passes, and prevents the rack from falling again, and at last all the teeth are gathered up and the tail of the pallet is stopped by the large pin K in the top of the rack, and the train can go no further.

The great feature of this English striking work is that you may 'strike' the clock as often as you like within the hour, or stop it any number of hours, and yet it will always strike right, because the striking depends on the position of the snail attached to the going part, and not at all on the number last struck. These clocks are therefore sometimes furnished with a string to the outside, from the click, so that you can pull it in the night and hear the hour. But this is just the wrong way of doing it; for if you hold the string too long the click will miss some of the teeth and the clock strike too many, and if you drop it too suddenly the rack will not have fallen its full distance and it will strike too few. The right place therefore to put the string is to the lifting piece, as at F. (The piece Q*q* belongs to something else which I shall speak of presently.)

Strike and silent. There are several ways of throwing the striking work out of gear, so as to keep the clock silent. I think the best, though not the usual one, is that shown in fig. 27, a small lever whose end *x* falls before and stops a pin in the rack when the

other end of the lever is put up to *si* by an index or handle coming through the edge of the dial. I have seen methods used which are very likely to stop the going as well as the striking of the clock, by leaving the rack to fall.

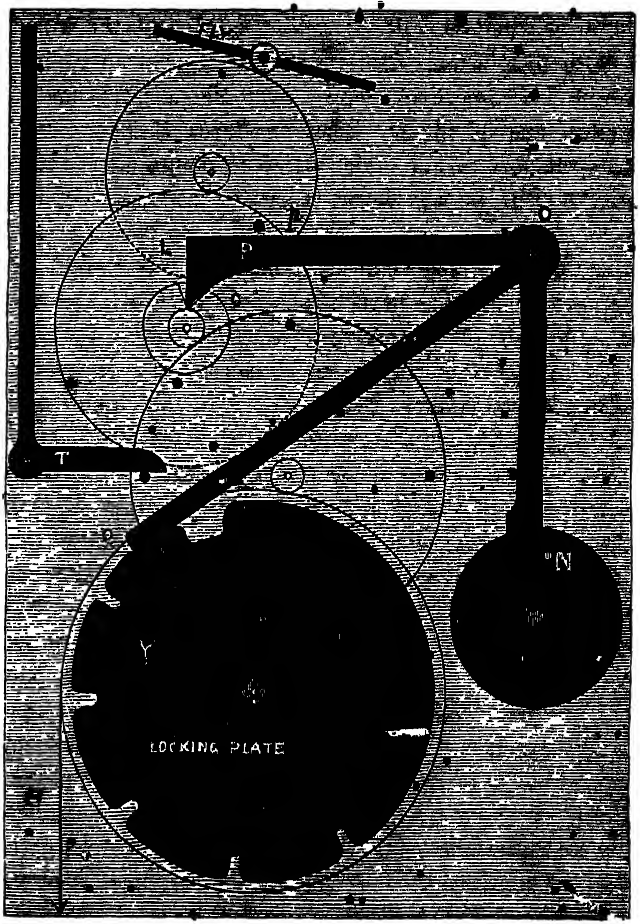
It may save people a little time if I tell them what hardly anybody seems to know, that you may move the hands of an *English* clock forward through all the hours without waiting for any of them to strike, except 12, where the rack-tail has to get over the great step in the snail; and even that is often provided for by sloping the front of that step and the face of the pin V, to let the snail push it aside, the tail being elastic enough to give way a little. In the same way the tail of the lifting piece at N is always twisted a little to let the lifting pin pass it backwards without lifting, so that you may turn the hands back and the clock will not strike at all, unless it has already given warning.

The snail is sometimes set on a separate wheel below the hour-wheel and moved by jumps by a pin in the minute-wheel M; this apparatus is called the *star wheel* and *jumper;* but I can see no use in it, and therefore shall describe it no further.

Locking-plate striking work. The principle of the striking work still used in all foreign clocks, French, German, and American, is shown in this drawing, though the actual arrangement of the pieces may be different. It is generally used also in English turret clocks. You see the rack and its click are gone, and instead there is a wheel Y called the locking plate or count wheel, which turns in the 12 hours and may therefore be put on the arbor of the great striking

wheel, or driven by the pinion of the striking wheel. It may be considered as marked out into 78 divisions, and notches made in it at the distances 1, 2, 3, &c.,

Fig. 28.



into which a lever O Q can drop, which is connected with the lifting piece. That is generally made with two stops upon it, one a little behind and below the other; and the pin P in the pin-wheel stops against the first when the clock has done striking, and against the other when the lifting piece is lifted by the wheel N in the dial work. But I have introduced an alteration in this respect in some turret clocks lately made, because one of the stops on the lever must be out of the right position for direct action of the pin. Instead of two stops on the lever, there are two pins on the wheel, P and p, one a little behind and nearer the centre of the wheel than the other, and p is caught by the stop when it has been lifted high enough to let the first pin P escape and 'give warning.'

There is, or ought to be, a disc C with a notch or cam in it on the arbor of the third wheel, which turns once for each blow, and moves faster than the locking plate, and therefore is more certain to lift the lifting piece quite out of the way of both pins before the pin-wheel gets once round; otherwise the clock might be, and clocks without this cam sometimes are, prevented from striking at all, especially if the parts are not adjusted with great precision. The lifting piece evidently cannot fall again until another notch in the locking plate comes under the tooth Q. Sometimes the lifting piece L O N Q is made in two pieces, one lifting the other, but I see no advantage in it, except where the pivot C happens to be at an inconvenient distance from the locking plate. In turret clocks with three-wheeled trains it is generally more convenient to make the wheel C turn twice for each blow, and then of

course there must be two cams, as shown in fig. 41. And I have also had it done by a small wheel with as many cams as there are pins, set on the arbor of the striking wheel, in small turret clocks where the striking is done by the second wheel as in house clocks, and the pins on the third wheel, the fly-pinion being the fourth; see fig. 31, page 187.

For striking *one* no lift by the locking plate is required, but only a long notch reaching from 12 to 2; and for the same reason the clock can be made to strike one at the half hours by dividing the locking plate into 90 (= 78 + 12) and leaving a wide notch between every two hours, and putting a half-hour pin into the wheel R (fig. 28) besides the hour one. Most of the French clocks are so made; but they have the inconvenience of striking one three times between 12 and 2. The far greater objection to the foreign plan altogether is, that if the striking once gets wrong, or stopped from not winding up, or let off by accident, or the clock stopped by housemaids, it strikes wrong afterwards, until it is struck round to the right hour again. The American clocks have a wire specially provided for this purpose, but the French have not, and you have to put your finger in behind the left side of the clock and lift the lever you will feel there, to make it strike as often as is necessary to bring it right; which is a great nuisance, and to some people almost or quite an impossibility.

Quarters. If the clock is to strike the quarters, a third 'part' or train of wheels is added on the right side of the going part, with as many bells and hammers as may be required. There is indeed a method of making the same striking part do both for the hours and quarters,

but it is complicated and probably saves nothing in cost, and of course requires a much heavier weight or stronger spring, and stronger wheels, if it is to be done effectively. The construction of the quarter part is substantially the same as of the hour striking part. If there are only 2 bells, the 2 hammers are lifted by pins on each side of the striking wheel, or they may be the same pins if the arbor of one hammer is put above that of the other. They should be so placed that the interval between each pair of blows or each chime is twice that between the blows of each chime, whether there are 2 or 4 bells. When there are more, the interval between each chime requires to be as much as 3 spaces instead of 2. When there are more than 2 bells the hammers are worked by a chime barrel, because the chimes are not generally the same thing repeated, as they are with *ding dong* quarters. But this belongs more to turret clocks, under which I shall go more fully into it. The chime barrel is generally put on the 3rd wheel, but it would require less force to turn it on the 2nd, for the reason I gave before, that the more wheels there are between a slow power and a quick work, the more is lost in friction, in a proportion beyond what anybody would expect. As the barrel naturally turns in an hour, the proportion of the pinion and great wheel would be just the same as in the going part.

The quarters may be let off either by the English repeating method, or by the French locking plate. If they are merely the same chime repeated 2, 3, and 4 times, the repeating movement should be used, as it has the same advantage as in the hour striking part. But if each quarter is a different tune, it should not be used,

because repeating the striking of the quarters in that case will throw the whole tune into confusion; though this plain distinction is often overlooked. The connexion between the two striking parts, when the quarters have the locking plate, is made by that wheel performing the function of the wheel N (fig. 27) in discharging the hour striking, as the 4th quarter finishes.

The repeating quarter movement is not so simple: the principle of it is this:—The quarters have a rack, snail, &c., just like the hours, the snail being fixed on the wheel N so as to turn in the hour, and of course with 4 steps instead of 12. The rack is so placed that when it falls for the 4th quarter (its greatest drop) it falls against the hour lifting piece somewhere between O and N (fig. 27) so as to raise it and the click C. It is then held up by the thing marked Q*q* catching hold of the pin close by it, and as the last tooth of the quarter rack is gathered up it pushes Q*q* aside again, which lets the lifting piece drop and the hour begin to strike.

There is a very simple construction of a clock for striking repetition quarters only when it is wanted in the night, by pulling a string which goes round a spring barrel, and so winds it up as far as it is allowed to go by the position of the quarter snail on the going part, which stops some pin or lever connected with the barrel. This may be easily made to indicate half quarters, for if there are 8 steps in the snail, then at about 50 min. past the hour the lever could go 7 depths and the clock would strike 3 *ding dongs* and one bell more; and it may either begin or end by letting off the hour. This construction is in substance that of *repeater*

watches, of which the striking part is both wound up and let off by pushing in the handle.

Alarums. If you suppose a short hammer instead of a pendulum fixed to the pallet arbor or the crutch of either kind of recoil escapement, it would swing backwards and forwards very quickly, and strike both sides of a bell of proper size placed so as to inclose the hammer. This is the way an alarum strikes, and not by the lifting of a hammer at distinct intervals. The hammer is driven by a wheel like a strong recoil crown escapement wheel (p. 34) with a spiked pulley or barrel attached to it by a ratchet and click, over which a rope goes, with a small weight at one end, and a smaller one at the other to keep the rope stretched and to wind it up by. The alarum can only go when a stop lever is lifted by a pin on a collar which is fixed on the hour hand wheel by a friction spring, so that it can be set to go off at any hour you like. You must not wind it up till within 12 hours of the time it is intended to go off, or it will go 12 hours too soon.

Tell-tale clock. This is said in one of the Parliamentary papers about the Westminster clock to be an invention of Mr. Whitehurst of Derby, for watching watchmen and telling whether they are on the watch and in the proper place all the night. That unpleasant little clock which one hears striking the quarters 3 or even 4 times in some Westminster Abbey afternoon sermons, is of this kind, and there are some in the lobbies of the Houses of Parliament. There are a set of spikes sliding in holes in a 24 hour dial, one for every quarter of an hour, which can be pushed in by pulling a handle in the clock case during a few minutes of that

quarter only. So if any pin is found sticking out in the morning it indicates that the watchman was either asleep or away at the time belonging to that pin. The plate carries the inner ends of the pins over an inclined plate or roller at some other period of the 24 hours, which pushes them all out again ready for work the next night.

Musical clocks. Clocks that play tunes—not short quarter chimes, but tunes of several minutes, either on bells or organ pipes, are not clocks in respect of their music, but simply musical boxes or barrel organs turned by an independent spring or weight and let off at the required time by a lever from the clock. And nothing else occurs to me as belonging to small or house clocks of sufficient use or importance to require notice. So I pass on to the larger branch of the art, which has been the subject of greater improvements within the last fifteen years than in the previous century, and has reached a degree of accuracy which was derided by a great authority among the clockmakers as impossible, when it was required by the Astronomer Royal for the Westminster clock, even after it had been very nearly achieved in that of the Royal Exchange. And this accuracy, equal to that of the best astronomical clocks, and very superior to that of chronometers, has been accomplished not only without an increase, but with a great reduction in the price of

PUBLIC OR TURRET CLOCKS.

It may be supposed that as the work of these clocks only differs from that of house clocks in the size of the hands and the weight of the hammers they have to

move, you will only have to enlarge the machinery and the business is done. But there is a very important fact in the way of that conclusion: viz., that as you increase the strength of machinery you increase its weight in a ratio as much higher as the cube is higher than the square of any of its dimensions; and when you increase weight you increase friction, and friction is a word which ought never to be long out of the mind of a clockmaker, or at least of a clock-designer, inasmuch as the timekeeping part of a clock is the only machine whose sole business is to overcome its own friction, resistance of the air, and variations of heat, and to do that in a constant and uniform manner. And there is this further difference between large and small clocks: in small ones the force or weight required to work a hammer of an ounce or two is generally about the same as is required to keep the pendulum going, and so the two 'parts' or trains are about equal in strength; whereas in large clocks the lifting of the hammer generally requires a great deal more power than driving the hands and pendulum, and therefore ought to have much heavier and stronger machinery. Nevertheless the object of some clockmakers seems to be to make the going train of large clocks as heavy and the striking train as light as they can, I suppose from the ridiculous love of uniformity which people have been taught for many years to admire in the great constructive art of building, and which is still more absurd in mechanics, except where the work to be done by two different machines is the same.

Pendulum. I have already treated of pendulums for large as well as small clocks at considerable length,

and there is little to add with reference to large clocks only. I will only repeat that the construction and suspension of the pendulum are of primary importance.

The great majority of clockmakers set their faces against large compensated pendulums, and will use nothing but wooden ones. And so long as the clocks themselves are no better than they are, it would undoubtedly be a waste of money to compensate the pendulums, as the escapement errors will far exceed the temperature one. But when you have got a first-rate clock in other respects, it is absurd to prevent it from going accurately by not giving it a pendulum, without which it cannot keep the same rate in hot and cold weather. It is true that a 2 seconds, or even a 1½ second compensated heavy pendulum, is a rather expensive affair if well made; and with a common dead escapement probably the advantage is on the whole in favour of a 13 feet pendulum of 2 or 3 cwt. over a 5 feet one of about half the weight, which will enable a clock with such an escapement as I shall describe to keep within a second a month of Greenwich time. The fashion of extravagantly long pendulums has very properly gone out, as their inconvenience and liability to be affected by the wind overbalances any advantage from them in a moderately good clock. There were several in Yorkshire until lately as long as 56 feet, or 4 seconds: 20 feet = 2¼ seconds, which old Doncaster church had, is the utmost length I should allow.

There is or was a practice in fashion with some clockmakers of hanging the pendulum to the wall above or at some distance from the clock, and connecting it with the pallet arbor, either by a long crutch pointing

upwards, or a horizontal rod, or both. Theoretically there is no objection to it, but practically it wastes a great deal of the escapement force in the friction and shake of the additional pivots, and renders a greater force necessary, or increases that quantity W*h* on which we saw that all the escapement errors depend. There may be cases, however, where it is impossible to hang a long pendulum in any other way; and then the only thing to be done is to take care that all the connecting work is as light as possible (a very thin wooden rod like organ 'trackers' is quite strong enough), and the pivots very small and well fitting, and that all the motion is exactly in the plane at right angles to the pallet arbor.

Position of clock. The worst of all positions for a large clock is the usual one, on a stool on the upper floor of a tower, for the reason I have already given at p. 94. The best is that which the authors of the memorial of the Company of Clockmakers against the plan of the Westminster clock were silly enough to call the worst, obviously because Mr. Dent introduced it, viz., on stone corbels built deep into the wall. Where this cannot be done, cast iron brackets bolted through the wall will do, or iron beams across the room if it is not very wide. When the clock is fixed as firmly as this, the pendulum may be hung from the clock frame if it is itself strong enough, and the pendulum cock properly fixed to it or cast with it, though the wall is generally to be preferred for a long and heavy pendulum, if the clock stands near enough to it. But again it is inconvenient to have a very large clock so close to the wall that a man cannot get some access to it from behind. Therefore no general rule

can be laid down for the fixing of turret clocks, except that firmness is the first consideration, to which everything else must give way according to the circumstances of the tower. I have already mentioned at p. 93 the increase of arc caused by hanging a heavy pendulum from the wall instead of a strong wooden frame from the ground—not a mere floor; and as the escapement errors vary inversely as the cube of the arc, the clock should go more than twice as well with the firmer suspension; and in fact it does.

Frame. The old established form of clock frame still used by all the London makers, I believe, except Mr. Dent, and by most of the country ones, is a sort of cage of vertical and horizontal bars, some of which contain the bushes for the pivots of the wheels, and have to be unscrewed from the principal bars in order to get any of the wheels out. It was a great improvement on this to fix the bushes themselves with screws instead of riveting them into the bars, as it enabled the wheels to be taken out separately, instead of all dropping loose at once and perhaps bending their back pivots as soon as the front bush was taken off. Mr. Vulliamy, I think, introduced this plan, and Mr. Dent used it in the Exchange clock, of which a perspective view is given in Tomlinson's Cyclopædia under *Horology*. But he soon afterwards adopted a still better arrangement, borrowed in principle from the French, who were strangely ahead of us in this branch of clockmaking, until the improvements introduced, or at any rate first adopted by him and the present Mr. Dent within the last few years.

The following picture, though dated 1850, shows accurately enough the general arrangement of a large

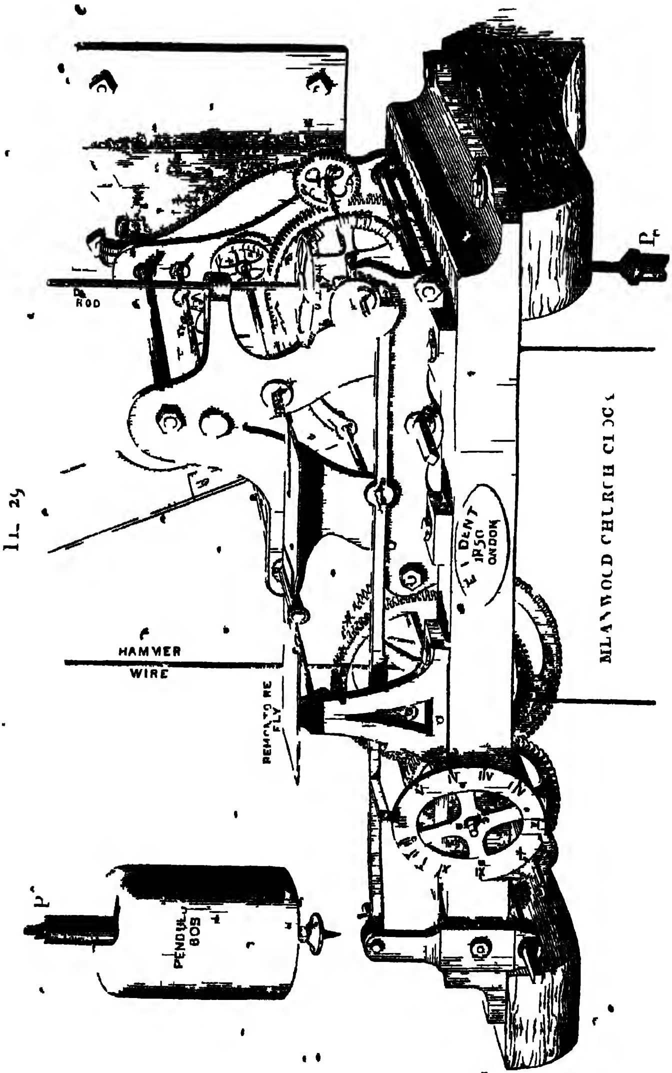


FIG. 29

MLANWOOD CHURCH CLOCK

clock of this kind, as I can easily explain the modifications which we have since made in it.

The great mass of the frame is a horizontal bed, cast in one piece, lying on the corbels and bolted to them. The arbor of the great striking wheel runs in large cocks bolted to the under side of the frame, and the great going wheel (though not so in the picture) runs in bushes lying on the top of the frame. The smaller wheels of the going part have their bushes in the A shaped small frame which rests on the great one, and they can both be taken out separately by unscrewing the bushes, and can also be lifted off and taken away all together in the small frame without interfering with the great wheel and rope. In like manner the second wheel and fly pinion of the striking part are set in the small pair of cocks of which the front one is shown in fig. 29 just under the words 'remontoire fly,' which we have nothing to do with yet. The great wheel has the striking cams upon it as shown at fig. 41, of which I shall have more to say hereafter. The locking plate wheel is driven by a pinion on the great wheel arbor, the pinion having as many teeth as there are cams, and the wheel 78, or any numbers in that proportion. The long levers which let off and stop the striking, are discharged by the snail in the going part, as will be evident enough to any one who is likely to read this description. I have given a separate drawing of the cast-iron pendulum bob with its domical top, as before described at p. 49.

Three-wheeled train. The superiority of such a frame as I have just described, in steadiness and convenience of arrangement, over one made of loose bars,

must be evident. You observe that both the going and the striking trains consist only of three wheels, instead of four or five as in house clocks and in most of the previous turret-clocks which went 8 days; and in the few which had 3 wheels it used to be accomplished either by very long barrels and a cumbrous frame, or by a large and heavy scapewheel with a great number of teeth in it, which I have already shown to be objectionable (see p. 96). Here it is managed, first by the use of wire ropes, which are about $\frac{1}{4}$ the thickness of equally strong hemp ones, and therefore 4 times as many coils will go on the same length of barrel; secondly by putting as many as 20 or 24 cams on the great striking wheel to lift the hammer (in an eight-day clock); and thirdly by driving the dial work from an auxiliary wheel of 40 teeth, instead of a pinion of some much smaller number, on a wheel of the train which must turn in an hour, as is shown in fig. 29. This wheel is either clamped to a collar on its arbor by thumb screws in very large clocks, or in small ones by a friction spring as in house clocks, and the discharging snail and bevelled wheels are fixed to the arbor. The great wheel in these clocks has never been made larger than 13 in. diameter (except of course at Westminster), and they are stronger for driving the dial work than clocks with much larger wheels driving through a small pinion, in the usual way. The great wheel turns in 3 hours only, which also makes the winding much easier than the usual plan of making the barrel turn in 5 or 6 hours, and saves an extra winding wheel on the barrel and a winding pinion, except in very large clocks.

In the French clocks of this kind in the 1851 Exhibition, and in Mr. Dent's original ones, the first bevelled wheel was on the great wheel, and therefore 3 times the size of the one it drives; but this involved some inconvenience with no adequate advantage, and so I suggested this other way of doing it. The second wheel turns in 15 minutes, and the scapewheel with 40 pins in 2 minutes, the pendulum being $1\frac{1}{4}$ sec.

In the striking part the advantage of putting the cams which lift the hammer on the great wheel is a great saving in the friction, and in strain upon all the work. This always used to be done in the old 30 hour clocks, and the consequence of doing it by pins in the second wheel in week clocks is, that there is hardly a large clock of that kind in England which is adequate to its work. The striking parts of York Minster clock had to be altered from a week to a day. For bells above a ton, I agree with old Mr. Reid, that one-day clocks are the best, except where there is an unusually long fall for the weights, as may be proved thus:—a 40 lbs. hammer raised to a height equivalent to 5 inches vertically is the least that will bring the sound properly out of a bell of that size, and that is too little if the bell is a thick one. Under the most favourable circumstances, and striking from the great wheel, you may reckon that the actual clock-weight will have to be double the theoretical, or $=40$ lbs. $\times$ 10 in. $\times$ 78 $\times$ 15 for $7\frac{1}{2}$ days, which will be nearly 9 cwt. with a fall of 40 feet; and if several cranks or pulleys are used, the weight will have to be a good deal more; and such large weights are not very safe in most places, and require a very strong clock besides. The Westminster

clock is the only one I know, where the proportion is much less than this, but there it will be seen that we adopted an unusual arrangement of the hammer-work in order to save friction and loss of power in every possible way. In the quarter part, where we could not do the same, the actual weight required is nearly three times the theoretical, and so it generally is. A one day clock of course requires a very much smaller weight, not perhaps $\frac{6}{7}$ less, because there is still a considerable loss by friction, but certainly $\frac{3}{4}$ less. There is however no difficulty in making the going part for $7\frac{1}{2}$ or $8\frac{1}{2}$ days (to cover a possible missing of the proper day), and I think the best plan is to make the clock-case so that only the clockmaker who has the care of the clock can wind up the going part, once a week, but to leave the striking part of such a clock to be wound up by a sexton or anybody else every day. In calculating the diameter of a barrel to suit a given fall of the weights, you must remember to make the actual diameter less than the calculated, by the thickness of the rope.

Some clockmakers still use wooden barrels, as they did when there was nothing better, 600 years ago. They shrink out of shape, crack, and decay, and are moreover unsuited to wire ropes, which are in every way better than hemp ones, lasting longer, and avoiding the necessity for either a long barrel or a very slow motion of the great wheel, and consequently a great strain upon its teeth and pinion. Some of the best provincial makers have begun to use them, and this pattern of clock generally, since the earlier editions of this book were published. The barrels may be

either of cast iron, which however is rather heavy, or sheet iron brazed at the seam, which is generally the best construction. The wire ropes should not be zinced, or (as it is called) galvanised, as that process makes iron brittle, and a mixture of tar and grease will much better protect them against rust.

The striking barrel must have a winding wheel for one of its ends, and a pinion with a squared arbor to wind it by, if the great wheel drives the locking wheel, because the arbor must then be fixed to the great wheel, with the barrel riding upon it. In very small turret clocks, with light hammers, and weights which do not require a wheel and pinion to wind them, the locking wheel should be driven by a single tooth or gathering pallet on the arbor of the second wheel if it turns once for each blow, or two if twice, with a spring click to keep it steady. But I think it is almost always better to wind the striking part by a pinion, in eight-day clocks at any rate, except in very small ones, as it enables you to have smaller pivots, and avoids a great deal of strain on the arbor, and makes the work easier. I have already observed that the old locking plate construction is nearly always used in turret clocks, as it is simpler and stronger than the rack or repeating movement, for which there is no such reason as there is in house clocks.

It is of great importance in fixing a clock to let the ropes have a long run from the barrels to the first guiding pulley, if they are not able to hang straight down without any guiding, as they seldom can; for otherwise the rope rubs against itself in winding, and wears out much sooner than if it runs smoothly on to

the barrel. This too is another advantage of the wire ropes, that as they require so much less length of barrel, there is less of this sideway strain and friction on them. In the Windsor castle clock Mr. Vulliamy used catgut lines with the same object, which enormously exceed the cost of wire, and are not so strong: but wire ropes had not been then invented. Mr. Dent was the first to use them after they were invented.

Stops for weights. There ought to be some strong stop fixed so as to catch the pulleys attached to the weights, or the ropes may get thrown out or strained at the end of the winding. In the Westminster clock the winding is stopped at the handle, but in clocks of common size without so much multiplying power, this is not requisite. Except where the floor under the weights is the ground, there ought to be a box of at least two feet of dry sawdust and shavings with a cover of wood, or still better, stone, over it for the weights to fall on if a rope breaks. Otherwise a heavy weight will go through any number of tower floors, and into the vaults below, as has sometimes happened.

I do not give any numbers for the wheels and pinions, because there is no virtue in any particular numbers. Every mechanic knows, I suppose, that high numbered pinions are driven more easily than low ones; and that the numbers of the wheel-teeth depend on those of the pinions. Much depends also on the work to be done. For instance, if the second wheel has to lift the hammer, it requires a much larger and stronger pinion than if it has only to drive the fly. Of the construction of teeth and cams I shall treat specially in a later part of the book.

I have sometimes found it possible to get a better division of the numbers of the wheels by making the cam plate C, on the second wheel (see p. 167), to turn $\frac{2}{3}$ round for each blow, instead of either once or twice; and as the blows of the hours are successively odd and even, that can be done. But for one o'clock having no lift in the locking plate, the cam plate might be made simply with 3 drops in it, of which one would always be passed over at each blow by the lifting lever without dropping. In order to get over one o'clock, for which the locking plate does not act, there must only be two drops at the distance of $\frac{1}{3}$ and $\frac{2}{3}$ the circumference from each other, and you must take care to set the cam plate in such a position that the lifting piece will have the long space on the circumference to pass over, and not the short, just before one o'clock or any of the odd hours. This is the case in the Westminster clock which goes 4 days, and in the Leeds town hall and Doncaster church clocks (see fig. 41), which are made to wind up every day in the striking part, for the reason I gave just now.

Four-wheeled trains. These horizontal frames evidently require rather more length than a well arranged cage frame, in which the wheels stand over each other; and they would require still more to contain a four-wheeled train. Turrets are sometimes made so small that a horizontal frame clock even of 3 wheels cannot be got in. The clock can be got into less length by making the frame something like a pointed arch which is also a strong form. Mr. Dent lately had an order for some clocks to be sent to Mexico, with unusually small limits prescribed for

them. The arrangement on the opposite page brings the work within the smallest possible limits, and I believe these are the strongest clocks of the size that have ever been made. There are no loose bars whatever to the frame, and instead of cylindrical bushes (fig. 30 *a*) which can only be let in near the middle of the bar, the bushes are mostly of the form in fig. 30 *c*, which admits of greater variety of position, and also enables the wheels and other pieces to be taken out singly with greater facility than the let in bushes. Another bush, which is used in clocks with horizontal and arched frames, is that of fig. 30 *b*, which is the best of all for convenience of fixing, and adjusting the place of the wheels, and taking them out separately.

Fig. 30.

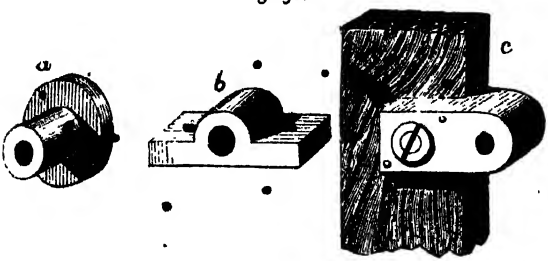
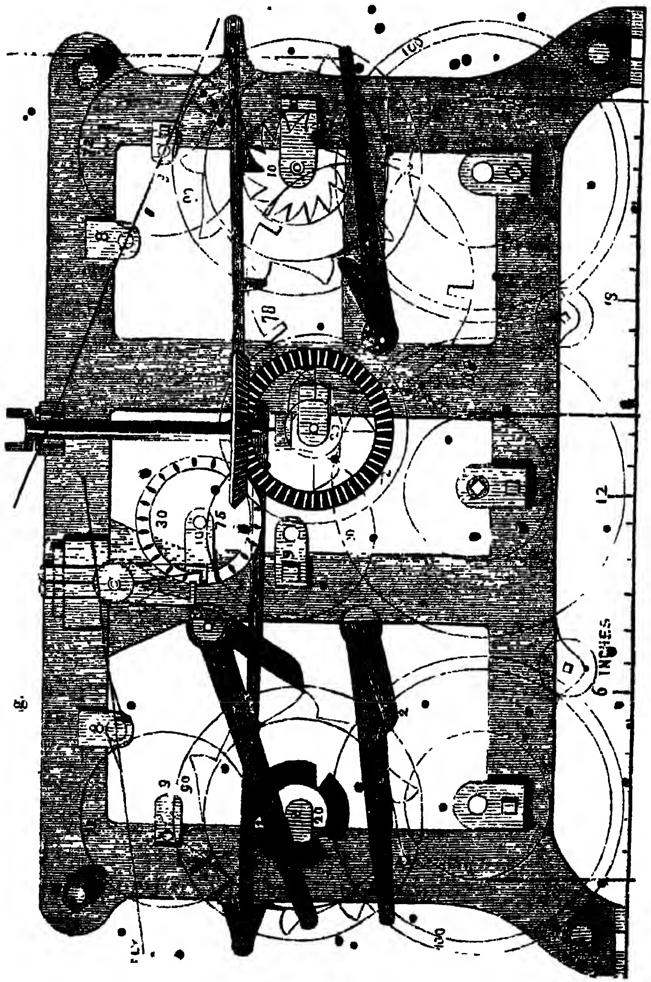


Fig. 31 is a front elevation of these Mexico clocks, showing as much as can be shown at one view without confusion, and representing the wheels only as circles for the same reason. They have 1 sec. compensated pendulums with bobs of nearly 1½ cwt.; where there is room, of course it would be better to use 1¼ or 1½ sec. pendulums. They are calculated to strike the hour on a bell of 4 or 5 cwt. with quarters in proportion, and will drive four 6 ft. dials very well. The whole length

of a quarter clock on this pattern is only 30 inches, and for one without the quarters 21 inches. The flies may require rather more, according to the size of the



hammers and the clock weights. One fly may go behind the other if necessary. I may as well remind architects that there must be room for a man to stand and wind up the clock besides. The hole in the upright bar where the pallets are shown, is only in the back bar, which is widened out for it, and the two lumps which form the pendulum cock are cast on the back. The cross bar which carries the locking plate 78 is only wanted on the front frame, and is omitted on the back one, as it would interfere with taking out the barrel. All the levers are so placed as to clear the ropes when they have to be taken upwards. The small cam wheel for lifting the locking lever of the striking part answers very well: that of the quarters is in fact the locking plate itself. If there are no quarters at the hour, the pinion of 26 should be 30, and it must drive a separate locking wheel of 36 which will turn in 2 hours.

Quarters. I have postponed part of what I had to say on this subject till now, because turret clocks have quarters much oftener than house clocks. Of the common *ding-dong* quarters on two bells I have little more to say, the construction being substantially the same in large and small clocks. When the quarters are struck at the hour, the first or highest quarter bell must be the octave above the hour bell, and the second a fourth below that: at least they sound very ill if they are not. But in my opinion it is a mistake to have the four ding-dong quarters struck at the hour at all. They are of no use whatever, and only waste people's time in counting and wondering what is to come; and they cannot be struck on the proper notes with a peal of less than 8 bells. But if you omit them at the hour, you

may have quarters of the proper notes on the 1st and 4th bells of a peal of six, or even five bells—the lowest number which is called a peal; and in a peal of ever so many bells you may then have your quarters on much heavier and louder ones, for instance the 3rd and 7th of a peal of eight, or the 5th and 9th of a peal of ten.

Cambridge and Westminster quarters. Where you have a good set of quarter chimes on 4 bells or more, with a different tune for each quarter, of course the case is different, especially as the tune at the hour is always the most complete of them all, as in the celebrated St. Mary's chimes at Cambridge, now for the first time, strange to say, repeated in a public clock, at Westminster on a much greater scale. How these chimes can have been so long admired by the many thousands of men who have all listened to them for three years, and yet never before been copied in a church clock, I cannot understand. Mr. Vulliamy once had an order for them for a turret clock for Lord Lansdowne, but unfortunately he assumed that they were on 4 successive notes, and got the bells and an iron bell-frame made first, and then wrote to ask me for the chimes, and found that his 4th bell was 3 notes too high, and the frame too small to hold one of the proper size. At the Royal Exchange they adopted the Cambridge notes, but, as old Mr. Dent told me, they pronounced the tune wrong, and altered it. I said that for any thing I knew, it might be wrong according to some musical rule, but that nobody could hear the Cambridge and the Exchange chimes without preferring the former, notwithstanding they were invented in the last century by a certain Professor of Law, not Music, whose

fame chiefly lives in some well known verses about 'a little garden,' by a much greater Professor—Porson. 'Well,' replied Mr. Dent, in his candid way, 'I heard those Cambridge chimes last year, and I must say they have a harmony about them that we have not got at the Exchange.' I should think they have: and in order that you may judge of them for yourself on a piano, if in no other way, I shall give them presently, together with a modification of them which I introduced for the purpose of adapting them to peals of 8 bells instead of 10, which the full Cambridge chimes require—except where they are merely the 5 clock bells as at Westminster.

Doncaster church quarters. In this case you *must* omit them at the hour, because the only bells that can be used for these quarters in a peal of 8 are the 2nd, 3rd, 4th, and 7th (reckoning, remember, from the treble always in peals of bells), and the hour struck after that on the 8th bell would be 3 notes too high and would sound very ill. The only reason why the slight alteration from the Cambridge tune is made in the 3rd quarter is to avoid the mechanical difficulty, or in other words, the expense, of a double hammer and cams for the 4th quarter bell—*i.e.* the 7th of the peal, which it requires to work it properly on account of its quick repetition. These 3 quarters on a peal of 8 however have the advantage of being more powerful than the full ones on the 1st, 2nd, 3rd, and 6th bells of a peal of 10, unless the 10 peal itself is enormously heavier. The quarters at Doncaster are heard at least twice as far as those at Cambridge. They have also been used at Scarborough (but the bells are thin and feeble), at Fredericton Cathedral, and several other

places now. You may even have them on a peal of 6; but you should take care that the hour hammer on the 6th bell is considerably heavier than the one which strikes on that bell in the quarters, to prevent mistakes.

Here are the several sets of chimes:—

Cambridge and Westminster.		Doncaster, Fredericton, &c.		Royal Exchange, (London).	
2nd	3126	1st	2347	1st	3126
	3213	2nd	4237	2nd	6213
3rd	1326		4324	3rd	1326
	6213	3rd	3724		3213
	1236.. 1st		7324		
			2347		
4th: 3126, 3213, 1326, 6213				4th: 3126, 6213, 1326, 3213	
hour 10		hour 8		hour 10	

That great bad bell of York, which has holes in it like the Westminster bell, by the same founder, and is of unequal thickness besides, might be recast into a more powerful (sound) one of only 8 tons, forming a very grand G hour bell to the B A G D bells of the peal, on which the Cambridge and Westminster quarters might then be struck. At present the bell is useless, and not worth using, and the clock goes very ill and is a bad one, though made by a London firm who boast of sending turret clocks all over the world.

The Cambridge chimes may be set on a barrel turning in any multiple of half an hour. It turns twice in the hour at Cambridge, where they wind up every day, and twice in 3 hours in the Westminster clock which goes 4 days. In the Doncaster clock, and others on that plan, the chime wheels are cast in two pairs, one of them with the great wheel, on each side of it, which

wheel turns in two hours; but all these arrangements may be easily adapted to circumstances. For heavy hammers all the cams should be faced with steel.

Chime tunes. These, like the musical work of small clocks which I spoke of before, form no part of the clock; all that the clock has to do with them is to let them off after the proper hour has done striking; the machinery is often in a different room from the clock: at the Royal Exchange the chime room is two floors below the bells, and the clock is above them, the connection being only by a wire. Chimes used to be much more common than they are: the machinery was very rough, consisting mainly of a large wooden barrel with pins stuck in it to pull the hammers. The barrel end has the rope coiled round it, and it drives two or three wheels ending in a fly to regulate the velocity. The hammer levers lie on a long bed which has a little end-way motion to shift for the different tunes, which shifting is generally done by the machinery itself, by a snail with steps, against which the hammer bed is always pressed by a weighted lever. I suppose modern chimes are always made with a cast-iron barrel, as at the Exchange, with steel pins screwed in to lift the hammers. Each bell generally requires two hammers for the blows quickly repeated, and the whole requires a very heavy weight to raise the hammers properly, and considerable space, as it is equivalent to the striking parts of a good many clocks put together.

Time of striking. The quarters are generally made to let off the hour, as described at p. 171. But where accuracy of time of striking is required, this plan is insufficient; for it makes the first blow of the

hour depend on the time both of letting off and of striking the quarters, both of which may easily vary several seconds. It is therefore essential to accuracy that the hour-striking should be let off by an independent snail of its own, exactly at the hour, with the quarters let off the requisite number of seconds before the hour; though the other three quarters may be allowed to strike at their proper times. Even this is not sufficient where extreme accuracy is required, as in the Royal Exchange and Westminster clocks, which were to satisfy the Astronomer Royal's condition of always striking the first blow within a second of Greenwich time. At the Exchange and King's Cross this is done by a train remontoire, which lets the train move by sensible jumps at every half minute, as you may see in the hands, and so there is no difficulty in letting off the striking lever exactly at the last jump of the hour. The hammer is also left 'on the lift,' or nearly ready to fall; which is in other respects also a good thing in a very large clock, because it relieves the wheels and the stopping pieces from a heavy pressure, and throws it all on the cams and hammer work, which must in any case be strong enough to bear it. In this case it is necessary to put a small click somewhere, to act on a pin in the fly arbor to prevent the train from running back when you wind up the clock: indeed it is as well to put one always, as the winding always tends to drive the train back. You may see them on the stopping pieces in the Westminster clock picture. Where there is no train remontoire, care must be taken to make the discharging snail large, and its corners sharp and hardened, and those of the discharging lever or lifting

piece also. It will be seen hereafter, that the accuracy of striking the first blow is secured in the Westminster clock by a still further provision, which had the effect of disclosing the inaccuracy of the common snail construction rather disagreeably in the quarters, until we put a larger and sharper snail, free also from the shake of the hands.

Regulating and setting of hands. I have already mentioned the two modes of attaching the leading-off work, or the wheels that lead to the hands, at p. 180. I have seen some clocks, and by makers of very large business, with no provision whatever for doing this, except either stopping the clock if it is too fast, or taking out the scape wheel bush and so setting it forward if too slow, which I need hardly say is abominable. A simple plan is to make either the scapewheel or the pallet arbor with one long pivot, with a spring end-stop against it, so that they can be drawn out of gear with each other, and so the clock put forward or backward. But there is some risk of damaging the scapewheel teeth in doing this, if you are not careful: I have seen them so damaged. The two ways mentioned above, or else a connection between the wheel and the collar by a square click and ratchet are the only proper ones. The only objection to the ratchet is, that the spaces can hardly correspond to less than a minute, and therefore you cannot alter the clock less than a minute. Another way of doing this would be to make the loose wheel slide on its arbor on a square, with a spring to keep it in its place, and then slide it out of gear with the great wheel and in again with different teeth in contact after you have set the hands. With the gravity

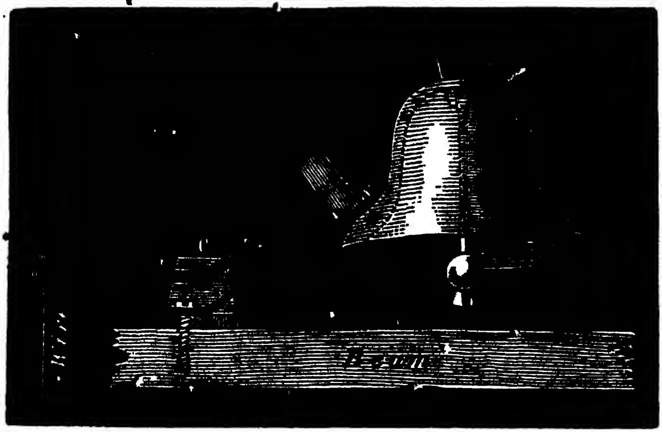
escapement however, you have nothing to do but to hold the pallets out of contact with the scapewheel, and put the clock back or let it run forward as long as is necessary, the velocity being kept in check by the escapement fly as it runs. These clocks therefore do not really require any hand adjustment, though it is generally added.

The small alterations for less than two beats of the pendulum ought to be done by a weight laid on the collar half way up the pendulum, which carries the small regulating weights described at p. 64. But very few clocks indeed will ever be altered for such a small deviation as this. I shall describe it more fully under the Westminster clock.

Clock hammers. Turret clocks always strike on bells of a different shape from the hemispherical house clock bells, which do not answer beyond a very small size, as I shall explain more fully hereafter. Most people are aware that the general shape of church bells is that shown in figs. 32, 33. The clock hammer C S is always fixed at right angles to the swing of the bell, for two very obvious reasons: first, if the bell was free to swing under the blow of the hammer, the first blow of every hour would set it swinging a little, and at every blow after that the bell would either be out of the reach of the hammer altogether, or else jarring against it; and another reason (if it is worth while to talk of other reasons after this) is, that if the hammer was put in front of the bell, all its machinery would have to be moved out of the way before the bell could be rung at all. I explain this very simple matter now, which I always thought too clear to require explanation before, because

it appears that a well-known omniscient teacher of mankind on all subjects, from an European war down to bell hanging, has somehow dropped this small piece of knowledge out of his Encyclopædia, and has told the world three or four times over during the last year that the Westminster bells are hung for the clock hammers

Fig. 32.



to strike upon them, 'contrary to all experience and 'common sense, so that they cannot yield the fraction 'of an inch under the blow of the hammer': the fact being moreover, that those bells are actually hung far more loosely than any church bell can be in the direction of the clock hammer, for the very reason that they have not to swing; and they do move under the blow of the hammers very sensibly—perhaps rather too much.

The hammers of large clocks also differ from small ones in acting by gravity, as you see. But they almost equally require a check spring, or some other con-

trivance, to keep them from jarring the bell: I say 'almost equally' because the hammers of small house bells are heavier in proportion than those of church bells, and so the effect of their being left to lie on the bell after striking would be much worse. When a church bell is rung *up*, *i.e.*, swinging once round for each blow, and *set* mouth upwards, the clapper lies on the bell, but not so heavily as a clock hammer would, because it stands at a higher angle. The usual kind of hammer spring is shown in fig. 32; and it is sometimes made adjustable, by having long holes for the screw to go through, so that you can bring it farther from or nearer to the bell as may be required in course of time. India rubber buffers under the hammer shank are better in some positions, and have the advantage of never breaking, and being easily replaced or altered in thickness. They must be kept from grease.

I believe it is the fashion on the continent to fix the clock hammers with their pivots above the bell, when it has not to swing; and it has the advantage of securing a long hammer shank, and therefore less angular motion for a given lift, and moreover the effective weight of the hammer is not so much lost in the lift as it is in the common position. But on the other hand, with bells as tall as the foreign ones are, the hammer shank stands much more vertically than in the other way, and the rebound from the buffers or check spring is greater, and a greater lift (obliquely) from the bell is required to get the same momentum of the hammer; not that that imposes more work upon the clock. At Westminster we were obliged to adopt that plan, on account of the construction of the tower and bell-frame, and there it had this incidental

advantage with regard to the great bell, that we were enabled to get the hammer tail T directly over the end of the lever in the clock, by setting the hammer

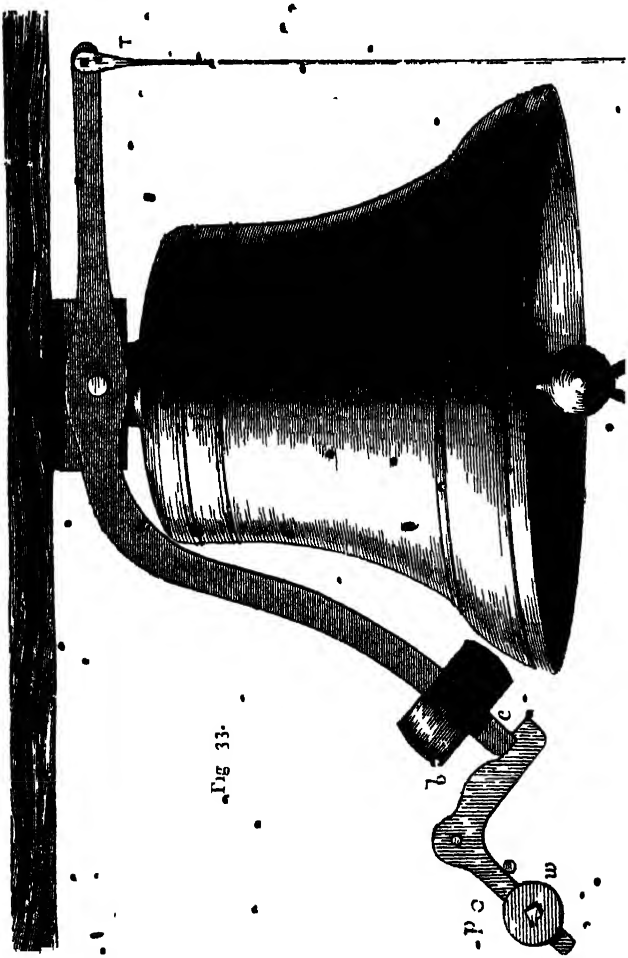
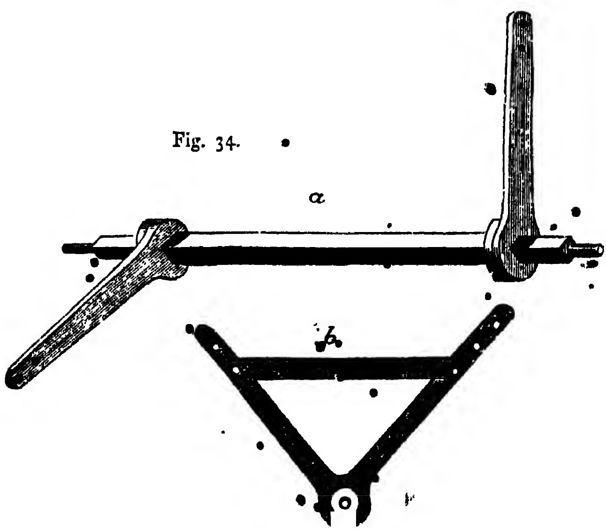


Fig. 33.

frame, or the pivots which carry it, a little out of the cardinal position relatively to the tower, and so all cranking was avoided and a vast quantity of friction saved.

Cranks. Nobody who has not tried it can have any idea how much of the force of a clock is wasted by having to lift the hammer through cranks. Where the hammers are not very heavy, you may sometimes use what I shall call *couple-levers* (for a reason which any mathematician will know), of the form in fig. 34 *a*, instead of a pair of cranks; but when the hammers are heavy, and the arbor of the lever has to be long, I find it is impossible to avoid some elastic torsion in it, which wastes quite as much force as the friction of a pair of cranks, and makes the hammers rise with a tremble, which checks the force of the clock and strains everything severely. For the same reason large cranks

Fig. 34.



should be made with a light connecting bar as in fig 34 *b*, which increases the strength enormously and helps to keep everything steady. The cranks and lever arms and hammer shanks and tails should all be long. I know that in modern towers, which are nearly always built too small even for properly hanging the bells, there is often great difficulty in getting room for clock hammers and cranks at all; but wherever there is room, the action will be easier and more effective if all these arms are made long instead of short.

When the clock is above the bells, as in the Leeds town-hall, and the Royal Exchange, it is a very common mistake to put a tail to the hammer to pull down first, which of course involves the necessity for another to pull up again. It ought to be done (if there is room) by pulling up at once from a lever set inwards or on the same side of the arbor as the hammer itself, unless it happens from some local peculiarities that this would involve as many cranks as the other way.

It has often been proposed to replace the hammer spring or buffers by a contrivance to catch the hammer at its rebound; but I have never seen any plan of the kind in action, or any description of one published. If it is worth doing, something of the kind which I have drawn in fig. 33 would probably answer. The end of the hammer shank in falling would push the catch aside by the belly *b*, and it would swing out of the way and not return quick enough for the hook *c* to catch the hammer until it has fallen on the bell, but would be ready to catch it at the rebound. The velocity of the return might be adjusted both by the sliding weight *w*, and by the position of the pin *p*, against which it strikes

when it swings away from the hammer. The only objection however to the usual spring or buffer plan is that it wastes so much of the force of the clock as is spent in lifting the hammer through the height it would have to fall to overcome the spring and just reach the bell. Sometimes too the hammer touches the bell again after the rebound, which however is of little or no consequence.

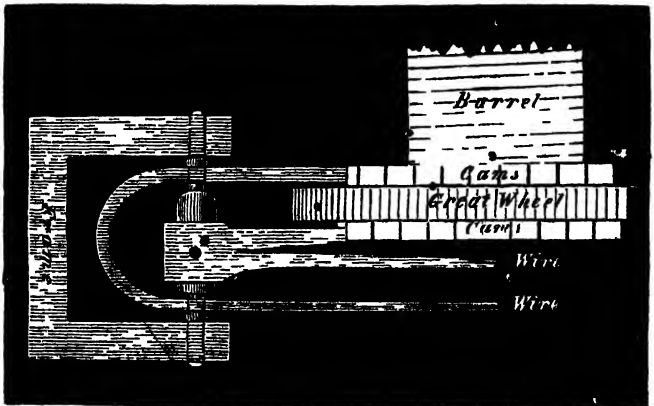
The weight of hammer, and its lift can only be determined by experiments. Different thicknesses and qualities of bells require different hammers. I have generally found that bells whose diameter = 12 × the thickness of the *sound-bow* or thickest part (which is the best proportion) require hammers nearly = $\frac{1}{10}$ of their weight to bring out the full tone, and I have seen some heavier. The lift of course has to be less for small bells than for large: the least that is effective in bells above 3 or 4 cwt. is 6 in. (measured obliquely in the direction of the motion), and beyond 13 in. we did not find any improvement in the sound of either of the great Westminster bells. Generally they are a great deal less either in weight or lift, and therefore you hardly ever hear a church bell sound so loud under the clock striking as in ringing with the clapper. Thin bells, as the larger ones of peals usually are, do not require such heavy hammers as thick ones; a lighter hammer and a higher lift suit them better; but it must be remembered that no hammer arrangement will get as good a sound out of a thin bell as a thick one, because it is radically inferior both in quantity and quality of sound. But I shall have more to say of that in the chapter on bells hereafter.

Lifting the hammer by pins on the striking wheel, as in figs. 27, 28, is totally wrong in large clocks, though it does well enough in small ones. The pins necessarily begin to act a good way from the end of the lever, and therefore at the greatest disadvantage as to leverage, and that at the very time when the hammer is rising most vertically (in the usual way of hanging) and requires the most force to lift it. The lifting should be done by cams, which begin to act on the end of the lever, and are properly shaped to act with the least possible friction throughout, as I shall explain under the *Teeth of Wheels*. Pins with rollers on them are of very little use, and do not obviate the objection I have mentioned, and I think they are nearly if not quite abandoned.

I have only further to remark in connection with this part of the clock, and indeed the going part also when the hands are heavy, that wherever it is possible, the force should act on the same side of every axis or arbor as the work to be done. Turret clocks are much oftener below the bells than above them; and wherever that is the case the hour hammer lever in the clock can easily be arranged as in the right side of fig. 41, the cams and the wire being both on the same side of the arbor of the lever, and the clock weight also acting between the cams and the wheel arbor. It is easy to see that if the diameter of the barrel were exactly as wide as that of the cam-circle, and if the hammer wire went straight up from the short lever, the striking of the clock would produce absolutely no pressure on either of the arbors, and therefore no friction beyond that due to the constant weight of the parts, which is

trifling. But if you set the wire, or long arm of the lever outwards (as it nearly always is), you must also hang the weight on the other side of the wheel arbor to make it pull the wire down, and whenever the clock strikes there will be *double* the weight of the hammer and of the clock weight on *both* those arbors, thus increasing the friction enormously. The same thing can be done, and is done in some of Mr. Dent's clocks, with a pair of quarter hammers fixed thus: with more than two it would be awkward.

Fig. 35.



I will add one word of warning against a piece of ignorance by which I remember a very fine old bell being cracked in a few months, viz. making the clock hammer to strike it with a sharp edge instead of a flat or slightly rounded face. The shape which I have given for a pendulum bob in figs. 8 and 29, inverted, is a very good one for a large hammer. The hammers of the Leeds and Westminster clocks are all of this shape.

DIALS.

Public clocks are oftener made without external dials than without bells, and particularly church clocks. Several of the cathedrals and the best church towers are not defaced with clock faces, as they must be wherever there is not a wide enough plain surface. In many others to be sure this consideration has gone for very little. Perhaps the worst case of all is the filling up of the tower windows of the magnificent church of St. Mary at Beverley with dials, and dials of the first degree of ugliness. The striking of a bell which can be heard all over a town is the thing which really regulates the public time; and it would generally be cheaper, better, and more convenient to put up a mere going clock with one or more dials of moderate height and size in a market-place, and to leave the striking to the church clock, doing it well there and saving the expense of dials, which must be larger and more expensive there than at a lower level in the market-place.

I have already alluded to the mistakes made by architects in not providing proper accommodation for clock and bell machinery, even in towers expressly designed for them. In most cases this only causes unnecessary expense and derangement of the works; but their ignorance of the proper size of dials often causes more serious inconvenience. Mr. Vulliamy did something towards correcting the common mistake of providing insufficient space for dials, in a pamphlet called *Considerations on Public Clocks*, which he published some thirty years ago. But it is probably forgotten now:

at any rate it has ceased to bear much fruit, when one sees such dials as those of the Leeds town-hall planned deliberately, in spite of previous warning, of about half the area proper for their height according to the well-established rule that the diameter should not be less than $\frac{1}{10}$th of the height from the ground. In order that anybody may judge of this for himself I will give a list of the sizes and heights of some dials which I happen to have got from Mr. Vulliamy's pamphlet other reliable sources, including one other besides those of the Leeds town-hall, which you will see, if you go to look at it, is evidently too small.

	Dials.	Diameter. ft.	in.	Height. ft.
Mechlin	1	40		
Westminster	4	22	6	180
St. Paul's Cathedral	2	17		126
Shandon Church, Cork	4	16		
Scarborough old Church	1	12		on a hill
St. James's, Piccadilly	4	10		
Bow Church	2	9		70
Manchester Infirmary	4	9		80
Royal Exchange	4	9		90
St. George's Church, Leeds	3	8	4	57
St. Martin's in the Fields	4	8		
Horse Guards	2	7	5	
Marylebone Church	3	7		about 60
St. Luke's, Chelsea	4	6	10	72
The Queen's Stables	2	6	10	about 50
TOO SMALL.				
St. Pancras Church	1	6	6	100
Leeds Town Hall	4	11		150

I once told some friends of mine who were building a church, also near Leeds, as it happened, that the dials, $4\frac{1}{2}$ ft. wide for 70 ft. high, would be much too small; the architect assured them I was quite wrong, and selected for his proof the dials of the Horse Guards and of St. Martin's, both of which he took upon himself to say, at a guess I suppose, were only 5 feet wide. His employers chose to believe him, and so the $4\frac{1}{4}$ feet dials were made; and they had not been up a day before everybody saw that they were much too small; but as usual, the mistake was found out too late to mend it. The Westminster and St. Paul's dials, you observe, and some others in this list, considerably exceed the proportion of $\frac{1}{10}$ of their height, and certainly do not look too large; and I have no difficulty in saying that that is the least size which a public dial ought to be, except in some unusual positions where they can only be seen a very little way.

An equal though not equally incurable mistake is often made in the size of the figures. People seem to fancy that you see what o'clock it is by reading the figures; as if any single figure which you see in a clock dial indicated the figure which you read off; except for the hour hand, and it is seldom that you do not know the time within an hour. You see the long hand pointing to VIII, and you say, '20 minutes to something.' Indeed for the hours as much as for the minutes everybody really judges from the position of the hand, and 12 large spots would do as well or better than figures. I have a clock, and there is another in the Athenæum club, with the gravity escapement, purposely made without any figures

at all round the principal dial, only 12 strong marks; and I never found anybody who even observed the fact that the figures were absent until it was pointed out to him, or complained of the want of them then. But you may ask what harm do large figures do? They practically contract the size of the dial, in two ways; first by contracting the plain surface in the middle, over which the hands are most distinctly seen; and secondly, the larger the figures are, the more they run into each other and fill up the space of the figure ring itself, and make it still more difficult to distinguish the place of the minute hand. I have come to the conclusion after various trials, that the figures and minutes together ought not to occupy above one third of the radius of the dial; the figures may be two thirds of that one third; and the minutes from half to two thirds of the remaining one ninth of the radius, with every fifth minute strongly marked by a larger spot than the others. The Westminster dials might have been clearer considering their great size. They are not of my design, except that I gave the architect some suggestions for them, which are partly followed and partly not followed. They are unnecessarily confused with iron frame-work, and the clear space is unduly contracted by some broad rings supposed to be ornamental.

The only colours that seem to answer for dials and hands are black or dark blue with gilt figures and hands, or some very light coloured ground, such as white glass, with black hands and figures. Good gilding will last fifteen or sixteen years, as at the Royal Exchange, in the worst London atmosphere: the Marylebone Vestry have to re-gild their church clock

hands every four or five years apparently. Gilt hands on a light ground are a complete failure. The external counterpoises, if there are any, should be painted the same colour as the ground of the dial, except where they are very short in proportion to the hands, as at Westminster, in which case they cannot be mistaken at any distance for the hands themselves, and practically increase their visible length.

Dials may be made of almost anything—stone, slate, plaster, brick, iron, copper, and many old ones are of wood, which however is the worst of all, as it always shows the joints. In many cases the stone of the tower makes the best dial. Generally it requires painting; but if it is such a stone and in such a position that it will keep nearly white, it will do very well with only the black figures and minutes painted on it, and black hands, but by no means gilt ones. Dials on brick work must of course be painted. It is quite a mistake to suppose that a dial requires a very smooth surface. Some of the most distinct I have ever seen are painted on rather rough stone work; and brick will do as well, either all flat, or with the figure circle a raised ring of iron, or of any plaster that will stand. There are many dials of cast iron; but I should never make more than the figure ring of iron, unless there is a large hole in the wall which wants covering; and even then it is generally better to fill it with glass, which has all the effect of a dark ground outside and is often convenient within. Slate makes a good dial, but if it is not painted, it becomes a pale grey colour. I believe 6 feet diameter is the largest size that can be got in one piece, but the joints are almost invisible if well done.

Copper dials are the commonest of all, and up to a moderate size, probably the cheapest, except of course when the dial is simply painted on the wall. But they are generally made in the very worst form that could be invented, viz. convex: the effect of which is that the point of the minute hand is thrown a long way off the dial, and the parallax is so great that you cannot tell what it is pointing at, except when it is nearly vertical; and moreover the convexity distorts the upper half of the dial when seen from below, as a public dial always is. To avoid these evils Mr. Vulliamy never used copper dials when he could help it, but flat ones, generally of slate, with the middle countersunk for the short hand to travel in, leaving the long hand to lie close also to the raised figure ring. And this is a very good form, for dials of anything but copper.

Concave dials. It occurred to me a few years ago that all the convenience of the light copper dials might be got, with even more closeness of pointing than in a flat one, and with as much stiffness as the convexity gives, and with less distortion of appearance, simply by making them concave instead of convex. If you draw a vertical section of a convex and a concave dial, and three lines of sight, from the top, the bottom, and the middle of each, to a spectator in the street, you will see at once that the convexity makes the upper half appear much smaller than the lower, whereas in the concave one the two halves appear even more alike in size than in a flat dial; and the closeness of the hand point is evident. Mr. Dent, and Mr. Potts of Pudsey near Leeds, a considerable maker of church clocks in Yorkshire, immediately adopted these dials,

and many of them have now been made, and some old ones altered from convex to concave with great improvement in appearance and distinctness. The dials on the platform at King's Cross Station, and the larger one on the Railway Works at Doncaster, were the first of this construction; and you may see from them how much better concave dials look than convex ones, and how close the minute hand is to the figures.

Hands. Large clock hands are so universally made of copper that it is hardly worth while to notice any other construction. There is indeed—or was, a notable exception, in Sir C. Barry's famous gun-metal hands at Westminster, which is not likely to be repeated. The hands of the clock at old Doncaster church, which perished in the fire of 1853, were of mahogany, and stood very well; but I should think copper ones are lighter, even including the stalk or centre piece. Where they are very large, say 5 or 6 feet long, the best form for them is that of the new minute hands at Westminster, a tube of thin copper, whose section is two segments of a circle, with a few diaphragms at intervals of about 2 feet to keep them stiff. The strength of this construction is enormous, and it is also good for throwing off snow, which sometimes accumulates on hands with broad edges heavily enough to stop the clock. Smaller hands may be made quite strong enough with a convex front and a flat back, the section being an arc and its chord, or even as a single flat piece of copper with the edges turned over square. A mere rib or hollow bead raised along the middle of a hand makes it strong enough for all ordinary sizes, but I think it does not look well. 'Galvanised' sheet-iron

hands have been tried, but the zinc peals off, and they must be pronounced a failure. The minute hand should always be straight, and plain, with a bluntish point. At the broadest part, or near the dial centre, it should be about $\frac{1}{13}$ of its length, tapering to about half as much a little way from the point. The hour hand should be the same breadth, ending just short of the figures in a broad piece called a heart, or any shape you like.

There should always be some external counterpoises to large hands, both for wind and weight. They should not be above $\frac{1}{3}$ the length of the long hand, and should be broad, but of a shape not to be confounded with the heart of the hour hand. The advantage of counterpoising the hands to some extent for the action of the wind is evident; and the other use of an external counterpoise is to diminish the tendency of the hand either to twist the arbor, or what is more likely, to work itself loose and shake over from one side to the other every time it passes the vertical, as Reid says the old hand of St. Paul's cathedral used to do, and as Sir C. Barry's heavy hands did at Westminster to such an extent as to stop the clock. The only way to prevent this shake is to fit the hands on a tapered square or hexagon at the end of the arbor, and not a prismatic one. The latter may be called engineers' fitting, and is perfectly right for many purposes, but perfectly wrong for this, for which the old clockmaker's taper fitting alone will answer. It is found better not to put the whole counterpoise outside: from one third to one half is quite enough, leaving the remainder to be done by adjustable counterpoises inside, which should be long

rather than short, as they then do the same work with less weight and friction on the arbor.

Illuminated dials. Occasionally it is possible, as at the Horse-Guards east dial, to illuminate a common white dial by reflection from a lamp on a roof projecting below it. This answers well enough for dials to be seen a short distance only, in the few cases where it can be done. Where it cannot, the common way is to make the dial of glass, or all of it except the figures and the rings to connect them, which forms a solid framework of cast iron. The glass is ground behind, or painted, or covered with muslin stuck to it, and gas lamps are put behind it. But all these things have such a bad appearance by day that the advantage of illumination is dearly purchased at that cost. Latterly however a white glass has been manufactured by Messrs. Chance of Birmingham, and perhaps by other makers, which forms a very good and always clean white dial by day (if left open for the rain to wash its face) and a bright one by night: the hands and figures must be black as with other white dials. This is not the glass used in the Westminster dials, which with the 2¼ tons of hands and counterpoises appear to have cost 5334*l.*, but a much cheaper kind, and as far as I can see, equally good. You may see it in Mr. Dent's small dials of the clock by the Marble Arch, Hyde Park, and contrast it with some other very inferior ones in the clock at the south corner of the same park.

There is another mode of illumination of which I cannot give a very accurate account; and it is yet so imperfect that I have not inquired particularly into it. It may possibly be improved into something better.

The dial is of common glass, with (it seems) a black screen behind it, but there are lights rather behind that, which can shine past the edges of the screen through the dial, none of them throwing the light downwards into the street; so that the dial generally looks black, or at least, dark. But the figures are ground, and the hands also are said to be of ground glass, which partly refracts the light in all directions; and therefore they appear light, and not dark like the dial. A still more wonderful attempt is now being made at the Leeds town-hall to get a *dark illumination* with metal hands, the architect pronouncing the white opal glass, which Mr. Dent was going to use, inconsistent with the design of his tower. The dials have already been curtailed to just half the proper area, chiefly from the foolish determination to have them illuminated at all hazards, for which it appears that no greater opening than 11 feet could safely be made in the walls. It ought to be understood too, that a considerable part of the area of an illuminated dial which is too large to be made of glass only, is necessarily lost by the iron framework, and therefore they ought to be, if anything, larger than the standard size of 1 foot diameter for every 10 feet of height from the ground.

The gas lamps of illuminated dials are generally kept alight all day, turned down as low as they can be without going out. They are usually turned down in the morning and up at night by a 24 hour wheel in the clock, which has pins screwed into its rim and taken out again from time to time by the man who takes care of the clock. So long as any of the pins are in the position to hold up a weighted lever connected with the gas

cock, it is turned down, and when the lever drops off it is turned up. In the Westminster and Leeds clocks there are three fan-shaped pieces on the 24 hour arbor, which can be opened out to 18 hours or contracted to 6, and these are adjusted from time to time according to the length of illumination required. There was a clock in the Exhibition of 1851 with completely automatic or self-adjusting machinery for turning gas off and on at the proper time throughout the year; but I never heard of it being used, and it is hardly worth the cost. Indeed there are very few dials which in my opinion are worth the original and the annual cost of illuminating them, which often exceeds the interest of the whole expense of the clock itself, and always exceeds the annual charge for winding and regulating.

It is desirable to have a wall, if possible, behind illuminated dials, instead of having them practically in the clock room; partly because the wall may be made useful as a reflector, and so save gas, and also because it protects the clock itself both from the variations of heat and from the watery vapour caused by burning the gas. It must be remembered also that the counterpoises of the hands on glass dials must neither be long ones outside, nor immediately behind the glass inside, or they will cast a shadow and be confounded with the hands at night.

The construction of the dial-work of large clocks differs very little from that of small ones. The principal difference is that the numbers of the wheel-teeth are differently distributed. Instead of two equal 60 min. wheels, there is a pinion on the minute-hand arbor which drives a wheel corresponding to the wheel

N in figs. 22, 27, 28, only moving slower; and that wheel has a pinion on its arbor which drives the hour-hand wheel as in house clocks. If $t\,t_1$ are the numbers of the wheels and $p\,p_1$ of the pinions, they have only to satisfy this condition, $\frac{t\,t_1}{p\,p_1} = 12$, bearing in mind also that, from their position, the radius of one wheel must be as much less than of the other as that of its pinion is greater. The larger wheel is generally put on the hour-hand arbor. The most convenient numbers are 90 and 100 for the wheels, and 25, 30, for the pinions, or in smaller clocks 72, 80 and 20, 24.

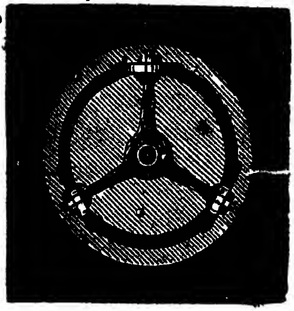
The bevelled wheels leading from the clock to the dials ought to be of a good size, not less than 5 inches wide in small clocks, and 7 to 9 inches in large ones. They do not require to be very strong, as they have only to move the hands; but the advantage of their being large is that any given amount of shake in the teeth allows less angular motion of the hands. In the old way of fixing clocks on a stool in the middle of the clock-room, which I have already shown to be the worst, there was generally a vertical rod from the clock running up the middle of the room, with 2 horizontal bevelled wheels, one on the bottom worked by the clock, and the other at the top working 4 others leading to each dial; and in that case it is necessary that the bevelled wheels on the vertical rod should be larger than all the others, both the first one in the clock, and the others leading off to the dials: otherwise the 4 leading-off wheels will take into each other as well as into the horizontal wheel. Where the vertical rod does not lead into the middle of the room this does not occur, but there must

then be two nests of 3 wheels each, if there are 4 dials, besides the 2 wheels in the clock. I have seen several more wheels added, through a singular piece of ignorance that it is not the least necessary that the rod which leads upwards should be vertical. I was rather glad that it was necessary to put it very oblique in the Westminster clock as an example of such treatment. With bevelled wheels of the common shape, intended to lie at right angles to each other, the rod must of course be in a vertical plane parallel to the clock wheels, but there can seldom be any difficulty in that: if there should be, the bevelled wheels have only to be made for the proper angle.

Sometimes oblique rods are used with universal joints at each end, and these will do well enough where the obliquity is not very great, provided always the oblique rod lies between two parallel ones; otherwise the velocity is not uniform. But where the obliquity is great there is considerable resistance to the motion, and a rigid rod with the bevelled wheels upon it is always better. Nevertheless universal joints, or half universal joints, are properly used wherever a rod is either too long to do without several supports, or where there is any risk of there being an unequal strain upon it in one direction, or where bevelled wheels can be saved by a jointed rod with very slight deviation from obliquity. Turret clocks are generally made with the minute-hand on the internal dial turning the wrong way round, to provide for the case of the external dial arbor being able to go straight through the wall from the back of the clock, as it does when the clock can be placed immediately behind a single external dial.

Sometimes the clock has to be placed a long way below the dials, 30 or 40 feet or more, and then it is necessary to provide both for the weight and the want of stiffness of such a long leading-off rod; and this is best done by a pair of friction plates and rollers at the top. The lower plate is set on the beams which carry the nests of bevelled wheels or *motion work*: on that lie three small flat cheese-shaped rollers on a horizontal tripod, with a hole in it for the long rod to go through quite loosely; and the other plate is fixed to the top of the rod, which is in fact hung by it, the rollers carrying the weight, and with no sensible friction on their own centres, for the three-legged pivots have no weight upon them. This kind of suspension is also used for heavy weathercocks which work a wind-dial inside the house, or elsewhere, like that over Mr. Dent's shop in the Strand; and the ease with which a very heavy weight can be turned in that way is surprising.

Fig. 36.



Weathercocks. As these are generally fixed by clockmakers in such cases as those last mentioned, I may as well mention that a weathercock which is intended to answer steadily to the wind, ought not only to be long in the vane and thin in the tail, but equipoised; and so far from the vane being perforated for ornament, it should be double, with the two flat sides or vanes spreading out at a small angle from the axis. When the cock works a dial it must be

fixed to a rod working loosely in a tube, and the top of the tube covered with an inverted funnel on the rod; as also the rods or wires which work the clock-hammers should be funnelled, with a short pipe soldered to the leads, wherever they are exposed to rain: otherwise the wires lead down the wet into the clock. And the weights and ropes should be enclosed in a case to keep them from the rain and wind, if they are in an exposed place.

Ventilation of clock-room. The clock-room at the Exchange was at first made with the object of keeping out the dust and damp in every possible way: even the slits in the floor for the ropes had sliders to them; the clock was enclosed in a glass case, the plate-glass cover originally placed over the escapement being found not enough to keep it from the damp. When the clock was repaired, and some of the brass-work replaced with iron in 1854 (for a reason which I shall mention hereafter), I suggested the removal of all this glass, and encouraging instead of preventing a draught through the room. This was done; and although the wet used to stand in drops upon the clock before in damp weather, it has been perfectly dry ever since. The same thing has been found in small clock-cases: they may easily be too air tight. I do not mean that there is any objection to enclosing a clock in a case, and of course it is absolutely necessary where the clock-room cannot be kept locked against everybody but the man who has the care of it: only there should be a draught through the room, and the case itself not too close to let air through it.

TRAIN REMONTOIRES.

I have postponed this branch of the subject till I had gone through all the more ordinary work of turret clocks. A train remontoire differs in principle from a remontoire escapement (of which I have already treated) only to this extent: the small weight or spring which gives the impulse to the pendulum is not wound up at every beat, but at some longer intervals, seldom more than half a minute; or the remontoire work, you may say, is put one step farther back, acting on the scape-wheel instead of on the pendulum. So that if a train remontoire of constant force and friction is made to act on a dead scapewheel, the only variation of force to which the pendulum is subject will be that arising from the pallet friction. In small clocks the variations of the pallet friction are generally much greater than of the train friction, and therefore a remontoire would be of little or no use; but in large clocks with heavy wheels and large hands to drive, the contrary is the case; and then accordingly, either a train remontoire or a remontoire escapement is of great use, provided they really do what they profess—which many of them do not.

The simplest form of train remontoire acting by a weight is that described in Reid's book, on the endless chain principle, which I have already described for a going barrel at p. 150. The scapewheel is not driven by the clock train, but it has a spiked pulley on it which carries one loop of the endless chain, and the other is carried by a similar pulley on an arbor driven by the train and turning in the same time as the scape-

wheel. This remontoire arbor has a few long spikes sticking out from it, at different distances along the arbor, and they are just long enough to reach the middle of the scapewheel arbor, and can slip past it through a nick cut for the purpose whenever the nick comes into the right position, which it does once in every turn of the scapewheel; then the remontoire arbor turns and winds up the endless chain a little until the next spike falls against and is stopped by the scapewheel arbor till its nick also presents itself and lets that spike slip through. There was a clock on this construction by Mr. Roberts of Manchester in the Exhibition of 1851, to which with great difficulty I persuaded the French members of the jury to concur in granting even a 'prize medal;' and I was rewarded by Mr. Roberts joining a party of equally disappointed and far more ignorant men in denouncing me for having prevented him and some others from receiving 'council medals' of the highest order.

Nevertheless that construction is far from satisfying all the conditions of a remontoire. The action of a chain cannot be made smooth and uniform, and a rope or string passing only half round a pulley is sure to slip in time, and so the remontoire would fail. Moreover Reid says that although the Edinburgh clock went very well for a time, yet it became necessary to remove the remontoire in consequence of the banging of the spikes against the scapewheel arbor; which however would be easily cured by a fly, and there was one in Mr. Roberts's clock and in the French remontoires which I shall next describe. There are three bevelled wheels S.T R which work together in the same way as I described for the

equation of time work at p. 148, except that they have each an independent arbor as shown in fig. 37 (which comprehends something else to be described presently). The intermediate wheel R rides freely on its arbor, which has the remontoire weight fixed to it, and which is always falling except at the moment when it is lifted

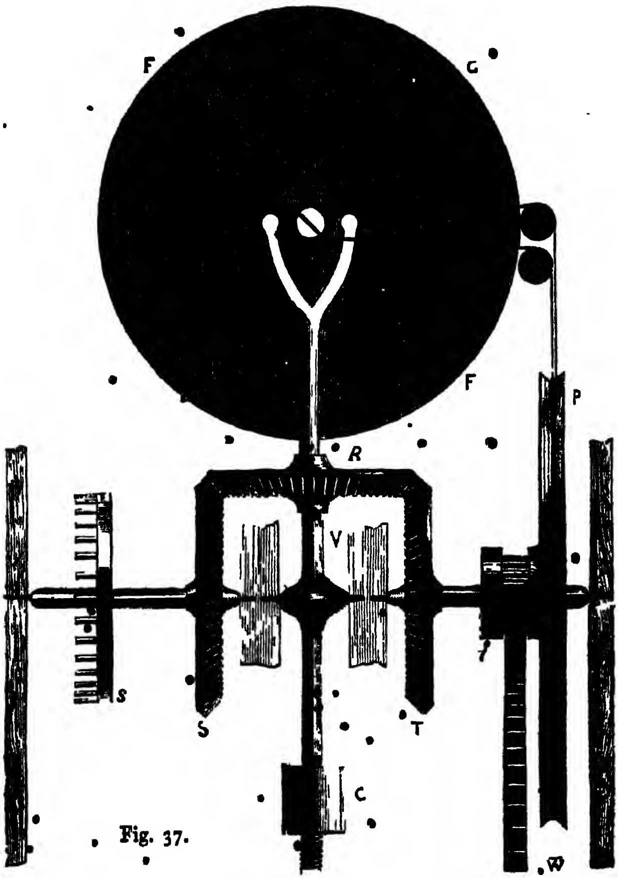


Fig. 37.

by the clock, through the pinion *t* in fig. 37; and then the action is not taken off the scapewheel *s* or its bevelled wheel S, but rather increased, as the wheel S becomes the fulcrum on which it is suddenly lifted. A common wheel on the arbor of T drives a pinion on another arbor (not in fig. 37) to which the two or three spikes are fixed which strike against the scapewheel arbor, and a fly to moderate the velocity of the train when the remontoire is let off, at every 20 or 30 seconds.

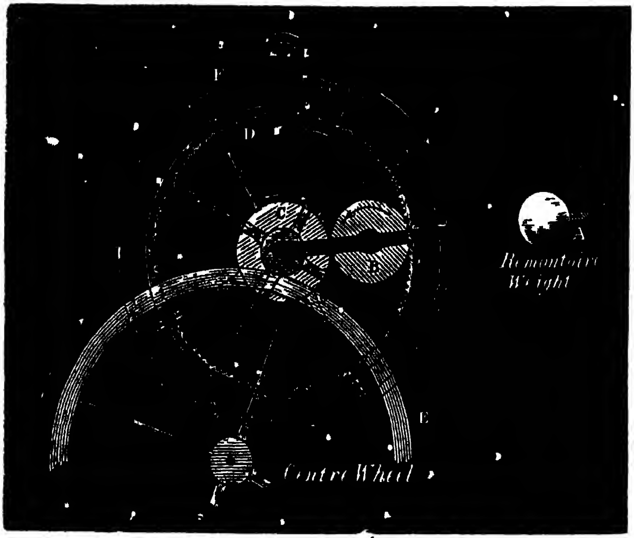
Continuous motion remontoire. In connexion with this I will describe a remontoire exhibited in 1851 by Messrs. Wagner, the great turret clockmakers of Paris, for the purpose of getting a continuous motion for telescope-driving clocks, or clocks to drive a barrel on which times of observation may be recorded at less intervals than a second, with all the advantage of a vibrating instead of a revolving pendulum. The action for the vibrating pendulum which is driven by the scapewheel *s* is exactly what I just now described, except that there is no spike wheel and no sudden letting off. Instead of that there is a large pulley on the arbor of the wheel T which lifts the remontoire arm C V R W. This pulley drives a much smaller one on the arbor of a fly F F, which runs inside a tin drum without a bottom, which is hung over it by two wires W W from the end of the remontoire arm. C is a counterpoise to be adjusted for the weight of the drum, so as not to let it preponderate too much. The fly is the thing which regulates the velocity of the clock train which is always moving; the farther the drum falls over it and cuts off the air within from the air outside, the

faster the fly will turn, and vice versâ; and things are so adjusted that the continuous motion of the clock train driving the fly will just keep pace with the average motion of the scapewheel driving the pendulum by beats as usual. If the clock falls behind the proper speed the remontoire wheel and its drum falls a little and lets the fly go quicker, and if too fast it rises and the velocity of the fly is checked. The one in the Exhibition seemed to go very steadily; and as there is nothing in all this at all difficult to make, I am surprised that more complicated contrivances should be used for such purposes as I have mentioned.

The Royal Exchange clock was originally made with a gravity remontoire, though it was afterwards altered. Instead of bevelled wheels, Mr. Dent, with the approval of the Astronomer Royal, used an *internal* wheel, *i.e.* one with teeth on the inside of the rim, instead of the outside. That wheel D in fig. 38 had the letting off spikes on its outside; at least a wheel on the same arbor had, which is the same thing. It was driven by the centre wheel of the clock, and whenever it moved it lifted the remontoire arm and weight by means of the small wheel B lying between the internal teeth and the wheel C on the arbor of the wheel F which drove the scape-wheel: that arbor being of course independent of, though in the same line with the arbor of the wheel D and its pinion. The remontoire was let off at every 20 seconds; which however is not so good an interval as 30, because it is not easy to distinguish whether the hands are pointing to 10 sec. before or 10 sec. after the half minute; whereas it is perfectly easy to see whether they are pointing to a minute or a half-minute, if the

dial is properly made, as I have already described. This facility for taking the exact time from the dial by the jump of the hands is one of the great advantages of a

Fig. 38.



train remontoire. I was sorry to be obliged to give it up at Westminster on account of the momentum of the hands, even without reference to the enormous additional weight stuck upon them by Sir C. Barry after the pattern hands were shown to me.

There is yet another way of making a train remontoire without resorting either to bevelled or internal wheels. In fig. 39 E is the scapewheel, and *e* its pinion driven by the remontoire wheel D which rides with its pinion *d* fixed to it on a stud in the remontoire lever A P. The centre wheel C drives that pinion and a

smaller one *g* on a wheel which drives another pinion *f* on the fly arbor, which has also the remontoire spikes

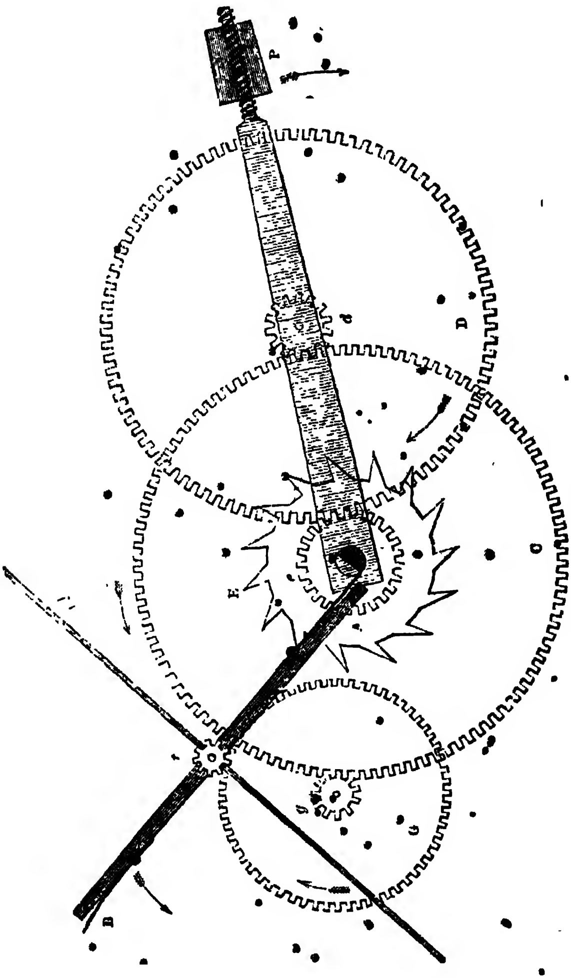


Fig. 39.

A B, attached to it. The numbers of the teeth are so arranged that the fly will turn once for each turn of the scapewheel, and the scapewheel arbor has only two notches in it, so as to let off one remontoire spike every 30 seconds. It is evident that the scapewheel is always driven by the remontoire wheels and weight, and not affected by the clock train. There were several French clocks of this construction in the Exhibition of 1851, but most of them (if not all) had the fly driven by an endless screw, which is objectionable because it involves an immense amount of friction, and in fact the motion of the train was so slow that you could hardly distinguish the jump of the hands. It is much better to diminish the blow on the scapewheel arbor by putting springs to the remontoire arms as in fig. 39, and leave the train to move with a good velocity so that the jump of the hands cannot be mistaken, as you may see at the Exchange, or the large dials at King's Cross, or the one over Mr. Dent's shop in the Strand.

Spring remontoire. But it must be observed that all these gravity remontoires are still subject to the friction of the remontoire wheels themselves, which is not inconsiderable, although it is much less and less variable than that of the clock train and hands. To avoid this, it was long ago attempted to contrive a spiral spring remontoire, which would drive the scapewheel without any sensible friction. One of these is described in Reid's article in the seventh edition of the *Encyclopædia Britannica*; and another was invented by Mr. Airy some years ago, and two or three specimens of it were made by Mr. Dent. They all went on the plan of connecting two wheels, or a wheel and pinion, on the

same arbor by a spiral spring, one being fixed to the arbor and the other riding upon it; and the consequence was that the scapewheel was always subject to the friction of the other wheel set upon its arbor and pressed tight upon it by the action of the spring, which was probably worse than the ordinary friction of the train.

This difficulty however may be got over by a very simple contrivance which I invented in 1849, and which is now in action in various large clocks, and would have been in many more but for its having been superseded by the cheaper and simpler gravity escapement already described (p. 125 to 139), which however has not the advantage of giving a visible motion to the hands at every half minute, unless it is combined with a train remontoire, as it easily may be. In fig. 40 (next page) E is the scapewheel and *e* its pinion, not fixed to the arbor of E nor riding upon it, but upon an independent stud *k* screwed to the clock frame. In front of the pinion a small bush is pinned on to the same stud, which carries the pivot of the scapewheel arbor, on which is set a large watch spring *s*, of which the outer end is held by a pin *h* screwed into a small plate fixed to the front of the pinion, so that the pinion acts on the scapewheel by the intervention of this spring without any friction except that of the coils of the spring upon each other, if they touch at all. The wheel D which drives that pinion also drives another on the fly arbor *f*. If the scapewheel turns in a minute, there will be two nicks across its arbor, as in fig. 39, for the remontoire spikes or stopping springs to act upon. But if it turns in two minutes, as the pin scapewheels

generally do, a different plan is adopted: the scape-wheel arbor is then brought through to the front of the clock frame and has a small steel cylinder set upon

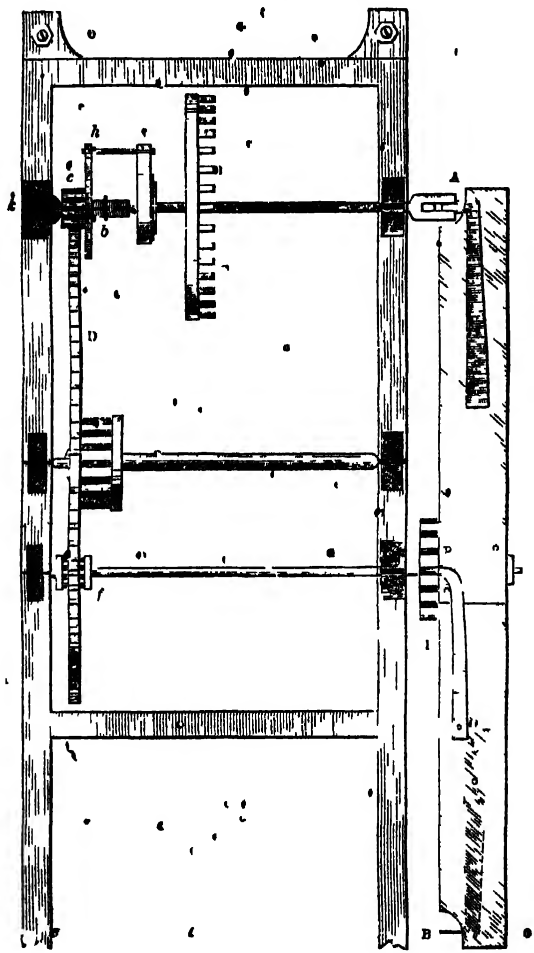


Fig. 40.

it, with two nicks across its face, not its side, one broad and shallow and the other deep and narrow; the remontoire springs set on the two arms of the fly have corresponding shapes, so that one will pass through the broad nick only and be stopped by the narrow one, and the other will pass through the deep nick but be stopped by the shallow one. The fly in this case makes half a turn for every quarter turn of the scapewheel, and therefore its pinion must be only half the size of the scapewheel pinion. In very large clocks such as the Exchange, in which the gravity remontoire was replaced by a spring one in 1854, the fly is made separate from the remontoire arms, with a ratchett and click as usual to let it run on a little by its own momentum; but in smaller ones it does very well to put the remontoire spring stops on the fly itself.

This was the construction of Mr. Dent's large clock in the 1851 Exhibition, now at King's Cross, for which a medal of the highest order was awarded to him unanimously by the Horological Jury, being proposed by one of the foreign members, and by the group of six mechanical juries, when I was not present, and by the Council of Chairmen, at which the proposer of that prize was present by special arrangement to support that award, and to oppose me as to some others on which the jury had been equally divided. I mention this because one at least of the disappointed candidates for a similar prize has several times published the impudent falsehood that I myself got that prize awarded for an invention of my own: as if moreover it would have been of any use to me if I had, seeing that I had taken no patent for it, and everybody was as free to

adopt it as Mr. Dent. I see there is now in the Crystal Palace a clock on this construction by another maker. The going of the Exchange clock was sensibly improved by the alteration of the gravity to the spring remontoire, though it had been unusually good before; and both that and the King's Cross clock have sometimes gone for two or three months together without any discoverable variation of rate; which also proves, by the way, that jewelled pallets and a 2 sec. pendulum are an unnecessary expense with this arrangement of the train, for the King's Cross clock has only a pin-wheel escapement, with steel pallets and 1½ sec. pendulum; but of course the escapement must be kept clean and properly oiled.

It may be supposed that the variation of the force of the spring in heat and cold will affect the escapement; and so it would if the spring acted directly on the pendulum like spring-pallets in a gravity escapement; but the effect of this variation of force when transmitted to the pendulum through the dead escapement is much too small to produce any sensible effect either on the arc or the rate of the pendulum. The outer end of the spring should not be left loose on the single pin *h*, but there should either be two pins, one a little behind the other for the spring to pass over, or what is better, it should be firmly fixed in a slit in the pin. This prevents the coils from rubbing upon each other, and keeps the spring steady in its place. The easiest way of adjusting it to smaller quantities than one turn of the remontoire fly arbor to get the proper vibration of the pendulum, is by having the remontoire arms connected with the arbor by a square toothed ratchett and a deep spring click, which can be lifted out and the ratchett turned

so as to set up the spring to any required amount. The larger adjustments are made by simply turning the fly arbor once round or more with reference to the scapewheel.

If this kind of remontoire were used with the three-legged dead escapement (p. 106), or with the detached one (p. 107), it should be let off at every half revolution of the scapewheel as in the Exchange clock, and the pressure of the remontoire pins upon it would be very small indeed even in the largest clock. A 2 sec. pendulum of 6 cwt., such as the Westminster one, might in that case be driven by a common watch spring wound up a little on the scapewheel pinion, at every 10 seconds in the detached escapement, or every 6 in the other. I should like to have an opportunity of trying that plan in a large clock. You cannot try different escapements satisfactorily in the same clock, for when you have once got to considerable accuracy, nothing but long trial with the pendulum firmly hung in its own place is decisive: mere trial in a clock factory subject to all kinds of disturbances will not do for accurate experiments.

Cast iron wheels. The success of this contrivance for cutting off the variations of force from the pendulum led to another alteration which helped to reduce the price of large clocks considerably, and that was the making all the wheels below the escapement, and all the dial wheels, of cast iron instead of brass or gun-metal. Mr. Vulliamy had before recommended that as a good construction for cheap clocks, but it had always been thought that they could not be also good ones on account of the greater friction of the

train. I believe that apprehension was very much exaggerated even for clocks of the common construction, provided of course the escapement is light and well made; but as soon as you cut off the friction of the train from affecting the escapement it is obvious that cast iron wheels are just as good as brass or gunmetal. The clockmakers in general violently denounce it, probably for no better reason than that it tends to lower their prices and has lowered them enormously, the price being now only 150*l.* for clocks of the same power and far greater accuracy than those for which 500*l.* used to be charged not many years ago.

The cast iron wheel controversy came to a head in some of the Lancashire papers soon after the making of the clock, from my design, for the Manchester Infirmary; and the advocates of brass wheels had nearly no case whatever. Their three points against cast iron were friction, rust, and liability to break. The friction of the train is absolutely immaterial with a remontoire, or a gravity escapement, and no large clock can go with great accuracy without some such contrivance. The next objection is obvious nonsense, because all except the acting surfaces are painted, and they are of course oiled as in all other iron wheel machinery. The liability to break is a mere question of experience. Mr. Dent has made the striking parts of nearly all his clocks for sixteen years of cast iron, and I never saw or heard of a tooth breaking yet, in either his or any other maker's cast iron clocks. Of course bad castings will break in clocks or bells or anything else; but a clockmaker who understands his business can easily see whether a casting is bad and can return

it. The people who talk in this way about iron wheels must be very ignorant of the extent to which cast iron wheels finer than are ever used in church clocks are used in every factory in Yorkshire and Lancashire. I made particular inquiries lately as to the sizes down to which the teeth are cast in iron wheels for spinning machinery (for that is what I mean by cast-iron wheels), and I found that they are cast with quite sufficient accuracy with teeth as small as $\frac{1}{10}$ inch thick; which is smaller than any I have seen used in clocks, because there is very little saving in cost in using iron wheels so small as that. The great saving of course is in the large wheels of the train, and the dial and bevelled wheels, of which a good many of the same pattern and no very fine pitch are required. I am glad to see that to this extent iron wheels are gradually getting adopted by some other makers; especially I may mention Mr. Potts of Pudsey, near Leeds, who has made many very good church clocks in Yorkshire, chiefly on the construction and pattern which I have described at fig. 29, only with 2 sec. wooden pendulums, which do well enough for all but first rate clocks instead of the more expensive $1\frac{1}{2}$ sec. compensated pendulums.

Before I leave the cast iron wheels I should observe that they work better with cast iron pinions than with steel ones: indeed cast iron and steel seem never to work well together, at least in no clock-work that I am acquainted with, if there is much pressure between them. I have seen cast iron fly ratchetts used with steel clicks, by clockmakers who would not listen to the proposal of iron wheels and pinions for any but the

commonest clocks, and Mr. Dent also tried them, but they had to be removed, and replaced either by wrought iron or brass ones. It should be remembered also by people who think they must be getting a superior article by ordering a clock with gun-metal or brass wheels, that they have no security for the quality of either, as they vary much more and also more invisibly than cast iron. I have seen and heard of brass teeth worn out in an almost incredibly short time, long before iron would show any signs of wearing. And similarly with regard to the pinions, ordinary purchasers cannot tell the least whether they are properly shaped or properly hardened, or in short whether the clock is worth half the money they have to pay for it. Moreover few people have any idea how rapidly brass is affected and in fact destroyed by such an atmosphere as that of London and other large towns. I have several times seen the brass tubes which had been used in dial work, and thin pieces of brass elsewhere, brought back to be replaced with iron because they had become, as one may say, completely rotten in the course of a few years. The small brass wheels of the Westminster clock and many others are painted, all but the teeth, instead of the absurd practice of polishing the surfaces to look smart for a few months, and then decay.

Mr. Vulliamy denounced that folly of polishing non-acting surfaces in his pamphlet on public clocks thirty years ago; but most of the clockmakers still follow it, no doubt because it is a great deal easier to do and more likely to captivate ignorant purchasers than taking care that the escapement is scientifically made, and a number of other things attended to which make

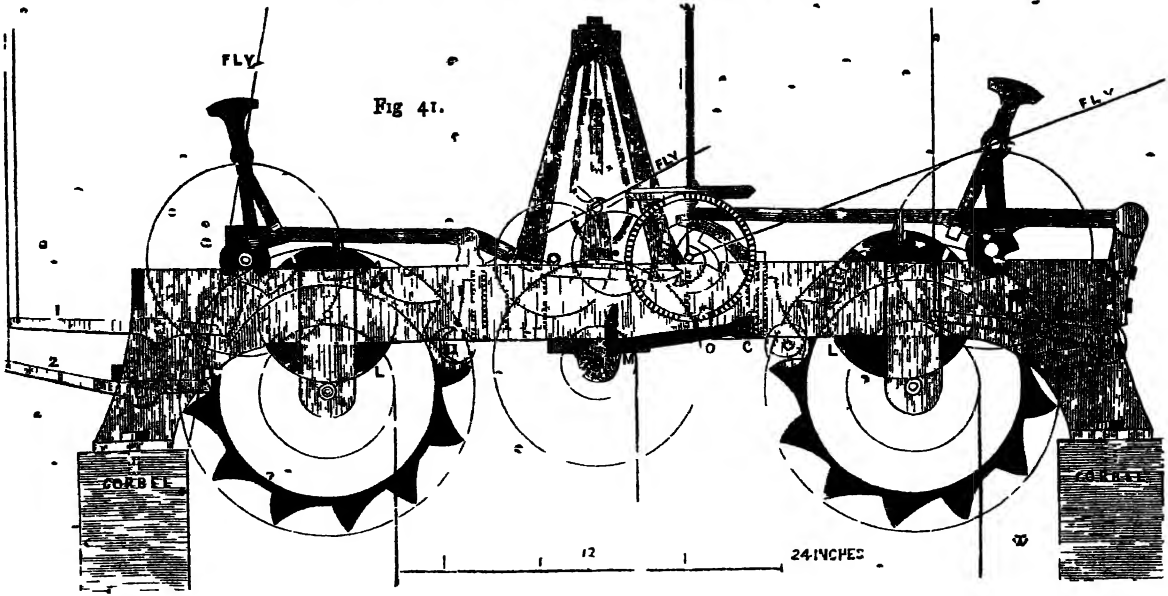
no show, but make all the real difference between a good clock and a bad one. I suppose it may be said without exaggeration that there is no machine made and sold in England, perhaps no article whatever in common use, which so few of the purchasers know how to judge of, and therefore in which imposition is so easy as turret clocks. In the great majority of places too there are not even any reliable means of knowing whether the clock goes well or ill. I have known nearly all the clocks in Leeds for instance several minutes wrong, except the one at St. George's church, which is a very good one, and which I knew to be right by a meridian instrument in the neighbourhood, but of course it was pronounced wrong by nine people out of ten.

GRAVITY ESCAPEMENT CLOCKS.

I have said at p. 125 to 139 all I have to say about the three-legged gravity escapement itself. I have now to explain the general construction and arrangement of large clocks with such an escapement. This elevation of one (fig. 41, next page), of what is called at Mr. Dent's the first size church clock, is rather different in arrangement from that given in the former editions, as I have transposed some of the parts in order to accommodate the same pattern of frame to all possible positions of the clock. It is not worth while to go through all the reasons for the alterations; it is enough to say that they are made because some inconvenience has been actually found on some occasion from other positions of the various parts; and if you alter this as

"QUARTER CLOCK WITH GRAVITY ESCAPEMENT."

Fig 41.



a general plan, you will probably find that you are in a difficulty either when the ropes have to go upwards, as they often have, or the dial-rod to go straight through from the back, or large flies to be used.

The going part is always made to go full eight days, and the numbers of the wheels are 120, 90, and 96, and of the pinions 10, 9, and 8, for a 1¼ sec. pendulum; for a 1½ sec. pendulum the last wheel and pinion are 90 and 9. The hour pinion has 40 teeth in all cases. The size here drawn, a 13 in. great wheel, is large enough for any church dials in England. The second size clocks have an 11 inch wheel, which is quite large enough for four 6 ft. or 6½ ft. dials. These clocks are really much stronger than the old patterns with a larger wheel and smaller pinion to drive the dial-work.

I have drawn the great pendulum cock of the height suitable for 9 inch pallets, as they have hitherto been made; this drawing having been cut before we had made any clocks with the double scapewheel (fig. 21) and shorter pallets, which is manifestly the best construction. It involves no alteration from fig. 41 except making the pendulum cock shorter, which is of course no disadvantage. The pallet-pivots are themselves set in the pendulum cock, the arbors lying close on each side of the spring. You must take care to leave room for the fly to clear the front of the cock or the piece which comes over to carry the front pivots of the pallet arbors; and there is no difficulty in this, because the natural arrangement is for the fly to be in front of the scapewheel even when it is single, and therefore of the pallets, which are of course in front of the pendulum top. The pendulum in these clocks is hung within instead of behind the

back bar of the frame to which the cock is bolted. Just in front of the pendulum is a much thinner bar attached at its ends to the large cross bars between the going and striking parts. This thin bar has only to carry the small cock for the back pivot of the scapewheel, and the fly and pallets and scapewheel come between that thin bar and another stronger one about 2 inches in front of it, which carries the bushes for the back pivots of all the going wheels, except the scapewheel, whose front pivot is carried by another small cock set upon that bar with a bush or smaller cock of brass upon its top of the shape proper for enabling the third wheel to drive that pinion; which any clockmaker of moderate ingenuity will easily plan for himself.

All these clocks that I know of have had only 1¼ seconds zinc compensated pendulums with bobs of about 1½ cwt., except Westminster, which is 2 seconds and 6 cwt., and Leeds 1½ seconds and 2½ cwt., which were so made because of the heavy dial works. There seems no doubt, from the experience of Mr. Dent, Mr. Cooke of Buckingham works, York, Mr. Joyce of Whitchurch, and Messrs. Cope of Nottingham, the principal makers of these clocks (though I have heard of others whose works I have not seen), that they go decidedly better with these comparatively short pendulums than the best dead escapement clocks with longer ones, unless they have also a train remontoire as described at p. 227. Nevertheless the usual rule will hold with this escapement as with others, that long pendulums are better than short ones.

The bevelled wheels are put in any convenient place to clear all the rest. The construction of this part of

the work is the same as explained already at p. 180. When the dial rod leads off backwards, of course no bevelled wheels are wanted. I have omitted for distinctness the regulating dial which stands on the front of the frame. There should be some half-minute marks painted on the third wheel, which turns in 90 seconds, to serve for a seconds dial to regulate the clock by.

The striking parts in fig. 41 are those of a clock not going more than two or three days, and striking the quarters on two bells, with none at the hour. The numbers of the wheels may be 96 and 90, with pinions of 12 and 10 for both striking parts; or the second wheels may be rather larger, with 105 teeth, as they are at Doncaster church; in both cases turning two-thirds round for one blow of the hammer or one chime of the quarters, as explained at p. 185. If the quarters are to be struck at the hour you must have about half as many more cams, and the second wheel must only turn half round for each chime. If the striking parts are to go $7\frac{1}{2}$ days there must be from 20 to 24 hour striking cams, in order to avoid an inconveniently large number of coils of rope on the barrel. For 20 cams the teeth may be 100 and 90, with pinions of 10 and 9, the second wheel turning half round. Of course these numbers are not essential, and any others in about the same proportions may be used according to the strength and size of the great wheels. The great striking wheels in these first size clocks are of cast iron $1\frac{1}{2}$ inch thick, with the cams of the same thickness cast with them; for very heavy hammers, say above 40 lbs., the cams are faced with steel. The second size clocks have striking wheels of 14 or 15 inches. A

wheel of this size with 20 cams is strong enough for a 20 lbs. hammer or a bell of 5 to 8 cwt. If it has only 12 cams and winds up every two days, it will do for a much larger bell, of a ton weight or more.

The Leeds town-hall clock, which raises the heaviest hammer in England after Westminster, has, like that, only 10 cams faced with steel; the wheel is 22 in. wide and 2 in. thick. In other respects the clock is very like fig. 41, except that there are no quarters, the Corporation having wisely determined to spend the money which merely common quarters and their bells would have cost, in an unusually large hour bell (see list of bells at the end of the book) and a clock capable of striking on it effectively, which is both far more useful and far more imposing in effect. It is a pity they allowed themselves to be overruled by their architect in the matter of the dials, which are a great failure.

When there are quarter chimes on four bells, the 3rd and 4th sets of cams (which should be the thickest) may be cast on opposite sides of the great wheel, and the first and second cast in another pair, and then all bolted together. In that case all the levers must be on one strong pin. The object of putting them as in fig. 41 for two bells only is to make one set of cams serve for both levers. I have only drawn a few of the notches in both the locking-plates L L to avoid confusion. The quarter locking-plate may be put on the great wheel arbor if you like, whenever the great wheel turns in some whole number of hours; but it makes the locking-plate rather inconveniently large, and therefore I have drawn them both as driven by pinions.

All the other details of these clocks have been already explained under their different heads, or are evident enough from fig. 41 to anybody who is likely to want them; and such persons will also perceive that I have omitted many lines in the drawing to avoid confusing it. The only wheels in the whole clock which it is at all necessary to make of brass or gun-metal are the two which drive the escapement, and their pinions are *lanterns*, which will be described hereafter. If anybody likes to have the 2nd wheels of the striking parts of brass driving lantern fly pinions, there is no objection to it; but the great wheels I should prefer of cast iron with the cams cast on, even if there were nothing to be saved in the cost.

I am sorry to have to add a word of caution respecting the hands in which these—or indeed any clocks of a new construction, are to be placed after they are made and fixed. I have been informed of several cases where they have beyond all doubt been wilfully damaged; and even without demonstrably wilful damage any clock may be easily made to go ill. In two cases the train remontoire had been found destroyed and of course the clock declared to have failed. In one of them (a clock of Mr. Dent's) Mr. Potts was engaged to restore it by a gentleman in the town, and the good going of it was then restored immediately. It is one more advantage of the gravity escapement clocks that they require less careful handling, and are less liable to damage from mere carelessness than any others, besides being quite as easy and cheap to make. I have never heard of any difficulty or failure in one of them, except in one or two cases from the escapement-

fly not being properly fixed at first, on which I have done my best to give clear instructions in the description of the escapement.

I will conclude this part of the book with a story which illustrates the value of public clock tenders better than any opinion I could express. A few years ago I was staying at a place in the north where they were going to put up a new church clock and had got a good many tenders for it varying from 60*l.* to 100 guineas; all engaging, as usual, to supply everything of the 'best.' I was asked to go to a meeting where the competitors were to attend, and help the churchwardens to elect a clockmaker. They were successively called in and I asked them a few questions as to their style of clockmaking. The first man that came in, after a few questions, begged to refer us to his foreman, who then took up the examination for him; nevertheless I had to pronounce them both decidedly 'plucked'—a word more generally understood now than it was a few years ago. Then came one whom I have several times mentioned, Mr. Potts, of whom I then knew nothing, but whose answers satisfied me that the job might safely be given to him if no better man came; and none did come, for 'the rest they ran away,' when they learnt what was going on, and that for once neither the lowest tender nor the most flaming promises were going to be accepted. The fact was that the low-priced clocks would have been dearer than the highest; and I was glad to find afterwards that that affair set a fashion for good clocks in the district and for many miles round, where but for that accidental 'competitive examination' by an examiner of some experience

at any rate, there would very likely not have been one public clock capable of going any better than a 5*l.* railway dial.

CONSTRUCTION OF THE WESTMINSTER CLOCK.

The frontispiece of this book is a front elevation of this great clock, or so much of it as can be shown in one view without confusion, for which purpose I have drawn the wheels and pinions only as circles. As I have inserted the numbers of the teeth, and the size of all the parts may be taken from the scale, I shall say no more of that, than that the frame is 15½ feet long and 4 feet 7 inches wide. The going part does not occupy above 2 feet of this width, the front bushes of the wheels being carried on a separate frame-bar lying on the two cross pieces of which the ends are shown in the drawing bolted to the great back and front girders. The space between the front of the going part and of the great frame happens to be convenient for the fall of the ropes from a double-barrelled crab (fig. 42), which is fixed upon the iron beams B B which go across the room from east to west to carry the 'motion work' or nests of bevelled wheels above the clock, of which the first pair are shown in the drawing. This crab is the only means of getting anything into the clock room which is too heavy to be carried by a man up the stairs. It consists of two small equal barrels with four pulley grooves in each, each having an equal wheel at the end turned by equal pinions on the winding arbor: over the page is an elevation of it. The rope passes over the outer halves of the two barrels 4 times,

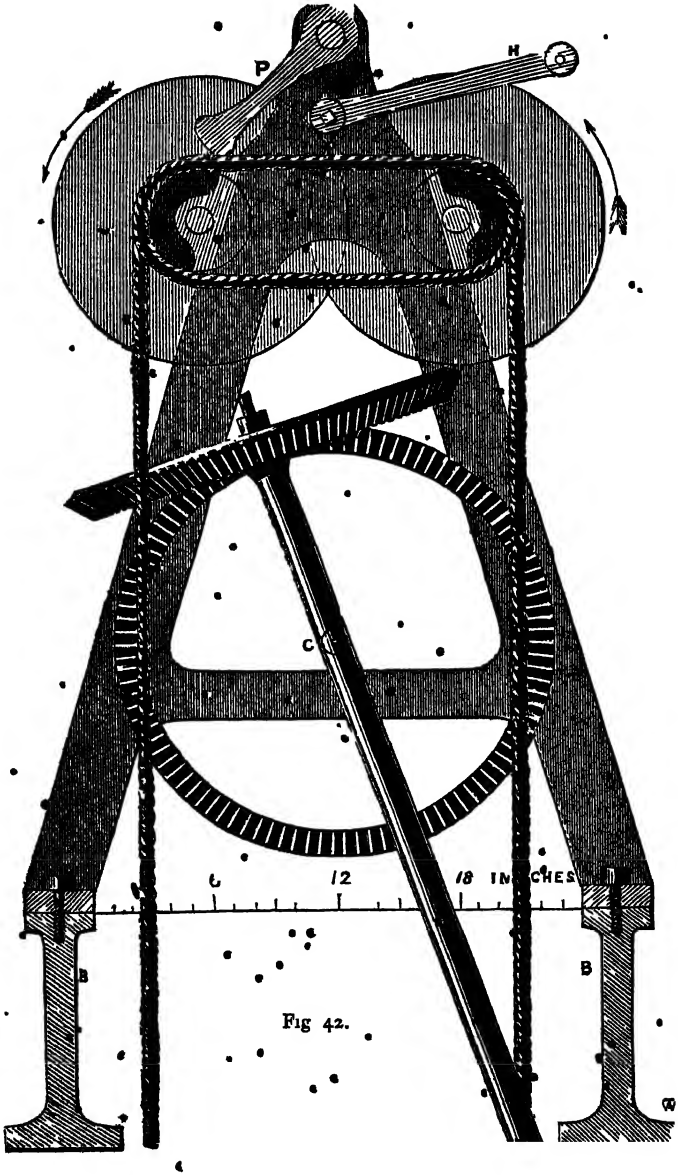


Fig 42.

one end falling down the clock shaft or well for the weights, as the other rises; and it can either be used with a single rope, or a double one through a pulley attached to the thing to be lifted, so as to double the power. I find it is not a new invention in principle, though I believe it is in arrangement; but whether new or not, it is certainly very little known, and it is so convenient and so much lighter and smaller than a common crab with its long barrel and heavy wheel and frame, and a rope coiled many times round, wasting power at every fresh lap-over, that I am surprised it is not in common use. The *pall* P is in effect a silent click to hold the rope when the handle H is let go. It will turn over on the horizontal pillar at the top of the crab, to act the opposite way when the barrels are worked the other way.

The back of the clock frame is 2 feet 5 inches from the west wall of the room, which is the east wall of the ventilating chimney or air-shaft of the Houses of Parliament running all the way up the tower. The room is 28 feet by 18, and the clock lies, as shown in the drawing, on the north and south walls of the shaft or well for the weights, which is 174 feet high, and the floor of the room is 2½ feet below the top of two iron plates which cover the walls and are spread out behind and built in quite through the wall of the airshaft, so as to prevent any possibility of endway motion of the clock frame, which is bolted to the plates. The pendulum cock is a large piece of iron frame work cast in one piece and also built in through the wall, quite independent of the clock frame. The pendulum chamber is made of sheet iron within the weight shaft, in order to

protect the pendulum from the wind: you can descend into it by a ladder and a trap-door; which can seldom be wanted, as there is a degree plate set on the floor under the clock, which is a little lower than the general floor of the room, and is covered with a grating lying on the beams which carry the returned end of the ropes.

Regulation. Here also is the apparatus for altering the clock by any quantity less than 4 seconds or 2 beats of the pendulum, for which various plans were proposed in the earlier discussions about the clock. There is a collar fixed on the pendulum 4 feet 10 inches from the top, to carry the small regulating weights described at page 65, $1\frac{1}{2}$ oz. there being equivalent to 1 sec. a day. There is also another large one of about 6 lbs., which fits loosely round the rod except at one side, so that it can be lifted off; if the clock is a little too fast this weight is carefully taken off, while they wind the clock up, until it has lost the requisite quantity, about a second in a quarter of an hour, and then it is put on again. If it is too slow it may be either be accelerated by laying on another similar weight which is kept in the room, or be first put on 4 seconds by lifting the pallets to let it trip one beat, and then made the 1 or 2 seconds slower by taking off the weight which lies on the pendulum; whereas you cannot put a dead escapement forward at all, nor back without some risk of injuring the teeth.

The pendulum weighs 685 lbs. altogether, which I suppose is much the heaviest in the world. Its construction is shown at page 56. From the top of the spring to the bottom of the bob and compensation

tubes is 14 feet 5 in. The zinc tube is 10 feet 5 in. it is made of 3 tubes put within each other and then all drawn together, and is nearly $\frac{1}{2}$ inch thick. In other respects the construction is that described at page 56. The pendulum spring is only $\frac{1}{60}$ inch thick, 3 inches wide and 5 inches long between the chops. The great pin through the upper chops has nuts on its ends to adjust it to the centre between the pallet arbors. The pendulum cock and the position of the clock floor are so arranged that a man 6 feet high may just stand upright with his head inside the cock so as to look square at the action of the escapement; which is, or will be when it is completed, for the clock-makers were 'locked out' by the Board of Works before it was finished, on the cracking of the great bell—

The double three-legged gravity escapement described at page 134. The scapewheel teeth are 5 in. long and the length of the pallets down to the stops is $10\frac{1}{4}$ inches; the teeth of the two wheels not being set quite hexagonal or equidistant, for a mere local reason not worth explaining. The pressure on the stops is only about 4 oz. The pressure on the pallets from an ordinary dead escapement wheel of 30 teeth would have been above 4 *pounds*; and if the clock had been made on the rival plan, which Mr. Vulliamy and the Company of Clockmakers tried to force upon the Government, with a 7-inch wheel of 60 pins, it would have come down upon the pallets with a thump of half a stone; and the pendulum would have had to make its way under the friction due to that enormous weight pressing on the pallets through the whole

vibration, instead of the insignificant friction due to 4 ounces acting only at the moment of unlocking; which is moreover so much relieved by the sloping of the stops, that I could find no difference in the experimental weight required to lift the pallets whether the scape-wheel was bearing on them or not. I found that in either case they only required an ounce falling ·9 inch at every beat to lift them, which is not quite equivalent to 12 lbs. of the 2½ cwt. (including the pulley) which is the going weight of the clock, or about $\frac{1}{24}$ of the whole. In other words, if the pendulum had a pair of horizontal arms only 9 inches long standing out from its top, an ounce weight laid on the end of each arm alternately at the beginning of every vibration and knocked off at the end, would be enough to keep it swinging 2° 40′ against the resistance of the air and such friction as there is in this escapement. The fly is nearly 11 inches long in each vane and nearly 2 in. wide: it is set on the arbor by what may be called a silent ratchet, or a steel-faced roller with stiff springs bearing endways against it, but obliquely, so that the fly can run forwards, but not backwards. It is almost impossible to make the escapement trip by any force you can apply to it by hand. Hitherto it has been going with the four-legged scapewheel (page 137), but the double three-legged in the Leeds clock is clearly better, and is ready to be put in.

Maintaining power. The going part of this clock takes about 20 minutes to wind up, and therefore none of the common maintaining powers would do. A bolt and shutter (see p. 153) might indeed have been made to lift higher than usual and so keep in action longer;

but then it would have to be very heavy, and moreover there was the risk of the man being interrupted while winding, or stopping to rest, and so letting it run out of gear or stick fast. Mr. Airy had proposed a modification of his Northumberland telescope apparatus, which I have already mentioned as having been used in the Exchange clock; but that is also liable to run out of gear, and is open to other objections; and so the following much simpler plan was adopted, with his full approval as soon as I suggested it. The barrel in any case would require an auxiliary pinion to wind it, taking into a wheel on the end of the barrel itself, close to the great wheel; and the only addition is, that the back end of the winding arbor runs in a loose bar, which hangs obliquely from the back pivot of the barrel (as shown in the drawing), and has a click on it which acts upwards in a set of ratchet teeth cast on the back of the great wheel. When the clock is going and not winding, these ratchet teeth pass under the click, just as in Harrison's going ratchet (page 151); but as soon as you begin to wind they stop the click and the bar from rising as it tries to do, and the great wheel itself thus becomes the fulcrum for the winding up of the barrel, and so the clock weight is for the time transferred to the great wheel.

The winding arbor fits loosely in both the bushes, because the back pivot and its bush in the bar gradually move a little upwards as the great wheel turns, while the front one of course remains fixed in the clock-frame. When it has moved as far as it was thought prudent to let it go, a long tooth on the winding arbor catches against a stop in the back frame, and the man

cannot wind any farther without turning the handle back a little to allow the bar to drop and the click to take up another mouthful of the ratchet teeth. The unusual length of the winding arbor, 4 ft. 2 in., makes this sideway motion insignificant for 10 minutes' motion of the great wheel: if the frame was narrower it could still be used, taking care to put the stop so as to prevent too much oblique action. Very few clocks take as much as 5 minutes to wind up the going part. If you take the trouble to calculate the pressure, you will find that there is rather more force on the clock in winding than usual; which however is of no consequence. If the winding pinion were larger in proportion to the wheel the difference would be greater; but it might always be equalised by hanging a weight on the loose bar, just enough to counterpoise the difference. The winding pinion pulls out of gear with the wheel in the usual way.

The dials are 22½ ft. in diameter, or very nearly 400 ft. in area, and are made of cast iron frame work filled with a very expensive kind of opal glass, which appears to me no better than some much cheaper glass of the same colour which is used in other clocks of Mr. Dent's. The dials and the hands together appear to have cost no less than 5334*l.*, which is about 2000*l.* more than the whole cost of the clock and all the striking work up in the bell chamber. I shall have more to say of this in the history of the clock. The minute spaces are a foot square, and the figures 2 feet long. The dials would have been clearer, and the hands more visible upon them, if the framework rings beyond the minutes and the figures had been omitted, as they

diminish the clear space in the middle of the dial by about one third of its area. The dials stand 5 feet from a whited wall which is the main wall of the clock room and clock-tower, and in front of which the gas lights for illumination are to be. I have nothing to do with this part of the business, beyond providing that the clock shall be able to light up and turn down the gas if required, in the way described at page 214. It is intended to have two sets of gas jets: one only small ones, to set light to the others, which will be turned completely off in the morning by the clock, but the small ones only turned down low. There is nothing peculiar in the dial-work except its size, which may be judged of from the drawing of the clock and fig. 42, and the fact that the minute wheel arbor is 8 feet long and 3½ inches thick; it is of course tubular, except at the ends. The dial centres are exactly 6 feet above the top of the walls, or 180 feet from the ground.

Hands. The minute hands, as now made by Mr. Dent from my design, are thin copper tubes, of a section formed by two segments of circles, with a few diaphragms soldered in, set on a gun-metal stalk or central piece, which also forms a partial counterpoise both for wind and weight outside, there being another of cast iron inside the clock room, to divide the pressure between the two ends of the arbor. This copper tube, or pointing part of each minute hand, only weighs about 28 lbs., though they are 9½ in. wide near the centre, running off to 5½ in. at the end; the gun-metal stalk of each hand weighs very nearly 1 cwt.; but the whole of that weight is near the centre, and so its moment of inertia at each beat of the pendulum affects the clock

very much less than if even the same weight were distributed all along the hand. The length of each hand and its external counterpoise is 14 feet; and the total weight of each hand with its external and internal counterpoises is now within 2 cwt., whereas Sir C. Barry's 4 minute hands and counterpoises (of which I shall have to speak in the history of the clock) weighed a ton and a quarter. His hour hands are still there; for though very bad in construction and three times as heavy as they need be, their motion is so slow that they do not sensibly affect the clock as the minute hands did, and so they may as well stay until they become unsafe. One of them has cracked already and had to be taken off. The hour hand arbor is a tube 5½ inches wide, and lies on large friction rollers both behind the dial and within the clock room. It was easy enough to put the clock room end of the minute hand arbor on friction rollers too, as it of course projects beyond the other; but at the other end it is managed by setting the pivots of 4 smaller rollers in a pair of rings screwed outside the hour hand tube, and cutting holes in that for the rollers to go through and reach the minute arbor, so that those rollers move in a 12 hour orbit of their own, besides the pair in action for the time turning on their own pivots.

Quarters. There is nothing very peculiar in the striking of the quarters. The position of the levers and cams is evident from the picture. The wires go up alternately on opposite sides of the winding-wheel arbor to prevent their fouling each other; and the 4th bell has two hammers because there is one place (as you may see at page 191) where the blow is repeated too rapidly

for a heavy hammer to fall and be lifted again by two successive cams, which would also have to be very short, with a great strain upon them and the levers. The hammers are all nearly $\frac{1}{40}$ of the weight of their bells, which I am satisfied, both from experience and authority of books, is the proper proportion for bells on this scale of thickness, which is that of the smaller and thicker bells of church peals, as I shall explain more fully afterwards. The levers are all $19\frac{1}{8}$ in. long, and their centre is nearly 36 in. from that of the wheel. The cams are of wrought iron with hard steel faces, screwed on to a cast iron barrel which is bolted to the great wheel, and they are constructed on the circular section which I shall describe for cams under the *Teeth of wheels.* Between the clock and the bell chamber there is another low room in which the cranks are, for leading off from the vertical wires to the 4 quarter bells. These wires are in fact wire ropes: I had them substituted for the iron rods which were at first used both in the quarters and the hour striking parts, and thereby got rid of an amount of concussion and noise in striking, which sounded as if the clock was shaking to pieces. Now the action in the clock room is so silent that you hear nothing except the bells and the passing of the click which stops the train from running back in winding.

Hour-striking part. The great striking-wheel has 10 cams $2\frac{1}{2}$ in. wide cast upon it and these have steel faces screwed on to them. The lever has a thick part in the plane of the cams and a longer and thinner piece lying behind the wheel and having the hammer rope attached to it, or rather a short rod with a swivel

and nut to take up the rope. The rope is half an inch thick, the same as is used for the striking weights, and is about 25 feet long and reaches up to the horizontal arm of the great hammer lever, which projects 5 ft. 4 in. from the pivots, which are forged as part of the collar in which the great bell hangs (see page 198). The hammer shank is also double, going through 2 holes in the cast iron head, which weighs near 7 cwt. and is lifted 13 in. from the bell, or about 9 in. vertically. There is an iron plate screwed to the hammer shank, which falls on india rubber buffers 5 in. thick, carried by a kind of long stirrup hung from the bell frame. The other hammers are prevented in the same way from jarring on the bells. The construction of the bell frame, which is entirely different from the usual form of frame for swinging bells, made it impossible to fix the hammers or the buffers in any other way: not that there is any objection to this, except that it is more expensive, and the hammer shank is farther from being horizontal.

The second wheel turns $\frac{2}{3}$ round for each blow, as I explained that it might at page 185, and the third wheel and fly make 4 turns for each blow. The fly arbors are placed vertically in order to get room for the flies, which have to be put near the top of the room. The vanes of the hour fly are each 2 ft. 4 in. square and extend 3 ft. from the arbor: the quarter ones are rather larger. To prevent all risk of accident, the ratchets are not pinned but 'squared' on the arbors under the flies themselves with an octagonal fitting, and each fly has two clicks. The stops are set on springs to diminish the blow at stopping, and the striking work

is stopped on the lift, both for accuracy of discharging and for diminishing the constant strain on the wheels and arbors. Each striking weight is nearly a ton and a half; and you may observe that each of the three parts is so arranged that the weight hangs between the arbor of the great wheel and the teeth or cams which have the heavy work to do, so as to reduce the pressure and friction on the arbors as much as possible. If this striking part had been made as they often are, and lifting by pins instead of cams, the weight would very likely have had to be 3 tons, or more than a man could wind up in a day.

The mode of letting off the hour-striking is peculiar. It was one of the original conditions, that the first blow of the hour should always be struck within a second of the real time; and in order to do this it was not sufficient that the clock should go far more accurately than usual, but there must also be the means of making the hammer fall exactly when the clock reaches the 60th second of the last minute of the hour. First then it was necessary to leave it on the lift and nearly ready to fall as soon as the striking part is discharged; and secondly, to have some more sudden and precise means of discharging it than the slow motion of a snail turning in an hour. It was at first intended to do it by the train remontoire described at page 228, with which the clock was made; but when it became expedient to remove this on account of the size and momentum of the hands after the dials were altered, it was also necessary to contrive some other plan for discharging the striking part with equal accuracy: and this is it. P Q is the ordinary discharging lever lifted by the snail

on the hour arbor, P being the first stop against which the arm E F on the third wheel of the striking train is stopped when it has done striking.* The second or warning stop D is not on P Q, but on a short independent lever C D. B A S is another lever set on pivots A on the cross bar of the great frame, and its heavy end

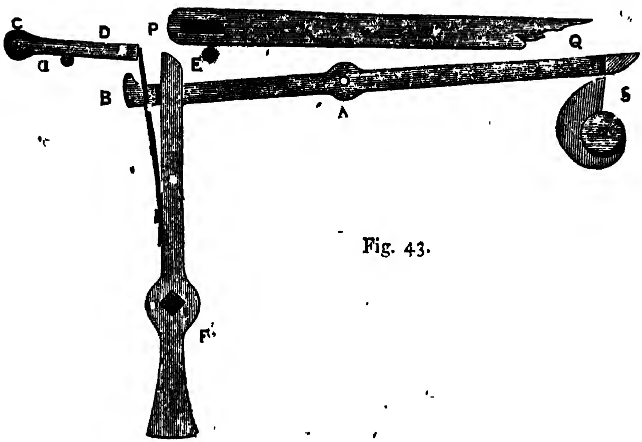


Fig. 43.

S is lifted and dropped by a snail on the 15-minute wheel of the escapement; when it drops it tips up the second stop lever C D, not merely by dead weight, but with a blow, which is certain to overcome any friction much greater than there can be between the two stopping pieces. Of course the lever B A S drops every quarter of an hour; but it does nothing to the striking part except when the stopping piece is resting against

* This lever, and several others, are omitted in the elevation of the clock (frontispiece), as they could not be shown without confusion; and as the snails are all shown, any intelligent reader will understand where the discharging levers must be: there is an intermediate one from the quarter snails to the quarter locking lever.

the second stop, *i.e.* when the clock has given warning for the hour. It is let off at the 58th second, or the last beat but one of the pendulum in the hour, and the train just gets far enough into motion to let the hammer fall as the seconds hand makes its last jump for the hour, and it acts with the greatest precision.

This precision in letting off the hour-striking made the want of it disagreeably apparent in the quarters, which were at first discharged in the usual way by a snail on the hour arbor which leads off to the dial work; and we had to put a larger snail for them on a separate arbor under the escapement wheels, free from the shake of the hands and dial work; this answers very well and there is never more than 2 seconds difference now (if so much) in the time of discharging the quarters. The 1st, 2nd, and 3rd quarters all begin to strike at those times respectively; but the 4th quarter is let off about 20 seconds before the hour, so that it may have done striking before the hour begins at the real time.

Winding. When the last edition of this book was written it seemed likely that the clock would require so much power to wind it that it would be worth while to apply some hydraulic apparatus, and I there suggested what seems to me the cheapest possible form of it. The fortunate cracking of the first bell however delivered us from that difficulty. It was cast by mistake so thick in the waist that it required a hammer of nearly 14 cwt. raised 14 inches to bring out the sound. The second bell only required a hammer of half that weight, and the winding of the striking part by hand is now quite easy and can be done by a man in considerably less

than a common day's work, and so all the cost of the hydraulic apparatus is saved, which I have no doubt would have been 1000*l.* at least, to say nothing of its being certain to get out of order sometimes. The third great bell must be made from the same pattern as the present one, to make sure of the same note, and as we may hope it will be cast soundly at last, it will not at any rate require a heavier hammer than the present one. Nevertheless if such a job had to be done again (which is very unlikely) and if the architect were not again permitted to construct the clock tower without any communication with the persons who were either to make or to superintend the making of the clock, it would be well worth while and perfectly easy *to make provision for driving the striking parts directly* by water; I mean not by a cast iron weight wound up from time to time by a hydraulic apparatus, which would be sure to get out of order sometimes, but by water alone running into buckets over an endless chain.* Here it was impossible; for (as you may see by the picture of the clock) it was only with difficulty, and by making the striking wheels and going wheels overlap each other, that the bare ropes could be made to fall on the proper side of the barrels, within the width of the clock-shaft from north to south; and it is very little consolation that it is 2 feet too wide the other way,

* I wonder it never occurs to the persons who suggest all sorts of ingenious plans for winding the clock by the tide, or the wind, or by people walking over a sort of weighing machine on Westminster bridge, &c., that any such contrivance would cost far more than the capital represented by the annual cost of winding the clock by hand, to say nothing of the additional cost of repairs, and the certainty of the thing sometimes getting out of order and leaving the clock helpless.

while the adjacent air-shaft was nearly as much too narrow for the width of a bell of the weight which was fixed upon before the tower was built.

The striking parts are made to go only 4 days, though it had been originally specified that the clock was to go a week; but I found that no man could wind either of them up in a day if they went a week; and if parts of two days were to be spent in winding, it was in every way better for the clock and easier for the winder to divide the week, instead of making the clock go for 5 days and wind for 2. Mr. Whitehurst proposed the same arrangement in 1847: he did understand something of the work to be done in striking a 14 ton bell: Mr. Vulliamy evidently did not, and his proposed striking part was altogether absurd. In that competition Mr. Dent was actually never told what weight the bell was to be, and understood or assumed that it was to be 7 or 8 tons, which weight was mentioned in the first correspondence on the subject. The going part of the clock will go for more than 8 days without winding; it is prudent to make that part go a day longer than the striking parts in all public clocks, so that if the man forgets the day of winding, the clock may not completely stop, but may proclaim his negligence by silence.

Winding stops. Another peculiarity arising from the great size of the clock and its weights is the necessity for stopping the winder whenever the clock has to strike; and I thought it safest to do this by absolutely pulling him up, and not to trust merely to a noise or some such warning. In each striking part a long lever (omitted in the frontispiece to avoid confusion) stands

in the way of a tooth or arm on the winding arbor: when the man begins to wind he must lift this lever up on to a certain hook which will hold it up so long as the weight of the lever rests upon it; but when the weight is relieved the hook falls back: this is done by the snail a few minutes before the clock is going to strike, and just a minute before it strikes the snail lets the lever drop again, and the hook being then out of the way, it drops completely and stops the winder; and the man then throws the winding-wheels out of gear.

This throwing out of gear is also done by a new method: the first pivot of the second (150) winding-wheel arbor is set in an eccentric bush, which can be turned in its own holes by a lever with a handle to it, as you see in the drawing, and the eccentricity is just enough to take the teeth of that pinion out of gear with the great winding wheel, leaving the 2nd wheel in gear with the winding-pinion (14). Besides this the ropes themselves stop the winder when the weights are wound up to the top, by throwing another lever off a hook on which it has to be set before the man can begin winding. In all these winding and maintaining power contrivances there are some further provisions for enabling the man to turn the winder back a little, to let the barrel ratchets down softly on to their clicks, but it is hardly worth while to describe them.

Provision is made in the clock for reporting its own rate of going to the Greenwich observatory at any convenient hour or hours every day, by electric telegraph, as I have already described under 'electrical clocks' at

p. 159; whether the Government will incur the expense of laying the wires to one of the telegraph stations in London, I do not know. Of course anybody can test the going for himself—as soon as the clock strikes the hours again, by listening to it while he looks at the timeball in the Strand at 1 o'clock, allowing for the velocity of the sound, which is about 4½ seconds to a mile; and perhaps that is sufficient without the other electrical connection. The history of this clock and its bells is remarkable enough to be worth preserving on several accounts, but it will be more convenient to finish all I have to say on the mechanics of horology first, and therefore I proceed to another subject the understanding of which is essential to a clockmaker, though not peculiar to his art.

TEETH OF WHEELS.

There are various treatises on this subject, and I only intend to say as much on it as it is necessary that a clockmaker should understand, if he means his wheels and pinions to run together smoothly instead of wearing themselves out by jerking and scraping, which I have known to happen in a very few years. The most comprehensive view of the whole theory of tooth-drawing (at least of this branch of the art) is in a paper by Mr. Airy in the 2nd vol. of the *Cambridge Transactions*, and it has been further expanded by Professor Willis in his *Principles of Mechanism*.

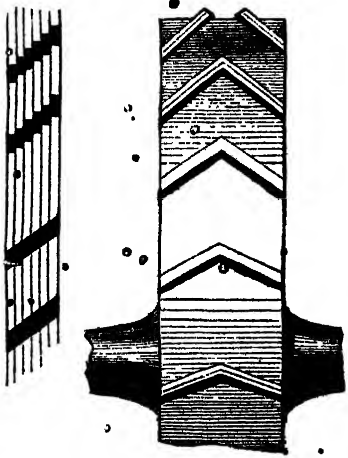
Some persons have a mistaken impression that the object to aim at in constructing wheel-teeth is to make them roll on one another without any rubbing friction.

This can indeed be done by what are called *involute* teeth, of the shape described by a point in a string unwound off the circumference of a wheel: but they are really useless, because they are so oblique that they produce a squeezing pressure between the two wheels which is more than equivalent to any saving in friction. The great thing to aim at in describing teeth is to make the relative velocity of the wheels uniform from the beginning to the end of the contact of each pair of teeth, which of course involves also the absence of all concussion or drop of the teeth. Another point is to have the action entirely or chiefly between the teeth which are separating from each other, and not between those which are approaching, which is commonly expressed by saying that the action should be after the line of centres of the wheels and not before it. The reason of this will be evident at once if you draw some teeth with a very rough outline so as to give an exaggerated view of the effect of friction, for you will see that there is a degree of roughness which will make the teeth jam against each other and not let them slide at all as they approach the line of centres, but that no degree of roughness will do this when they are leaving contact or are past the line of centres. The most perfect thing is when the contact takes place for a very short distance only close to the line of centres; and this can only be with very small teeth, and therefore very high numbers (except with involute teeth, which I have already said will not do for another reason). There is indeed a well-known contrivance for getting this kind of action with large teeth in heavy machinery, by putting several large-toothed wheels close together,

with the teeth of each a little behind the other, but this is never used in clockwork.

Helix-teeth. A modification of this plan however, very unlike it in appearance, has been occasionally used in clocks under the erroneous name of the *helix lever*. The teeth certainly do at first sight suggest the idea of an endless screw, but they are essentially different, the arbors being parallel, and not at right angles as in an endless screw. If you suppose a good many very thin toothed wheels put together side by side, each with its teeth a little behind its neighbour, they will present a surface like a rough tooth with a sloped face, as in the upper part of this figure. Then go a step farther and suppose the rough edge to be smoothed off, and the result will be a smooth-faced oblique tooth, like the lower one in the figure, which will drive teeth of corresponding obliquity on another wheel, and the contact will be solely at the line of centres, where there is no friction. But when the teeth thus become smooth, there will evidently be a great endway pressure on each arbor, which there is not while the teeth are square, or belonging to separate wheels put together. This endway pressure may however be neutralised by again

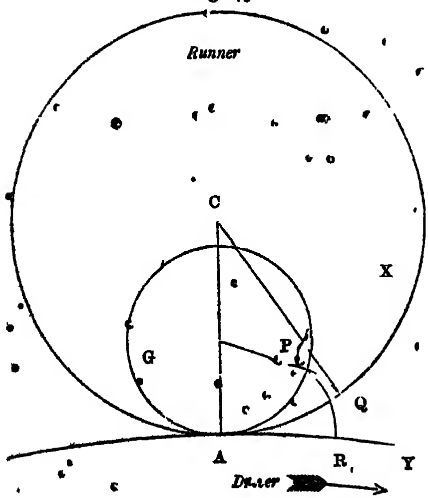
Fig. 44.



putting two such wheels together with the teeth sloped opposite ways. I understand this is called White's Gearing, but I do not know of it being used anywhere now. There was a German turret clock on this plan in the 1851 Exhibition, which certainly went with a very small weight; and small clocks with the single helix tooth had been made in England many years before by Mr. C. Macdowall (whose escapement is described at p. 104) which also required less force than usual, from the smallness of the friction in the teeth. I do not know that the advantage is worth the expense; but as this construction is very little known or understood, I explain it in case it may be turned to any use hereafter.

Epicycloidal teeth. It may be said without exaggeration, I believe, that all the teeth now used in machinery are constructed either as epicycloids or hypocycloids, and the meaning of those words is this:—If you roll a circle A G P *on* another circle A R Y, the curve R P traced by any point P in the rolling circle is called an epicycloid to the circle

Fig. 45.



A R Y; and if you roll the small circle A G P *within* a larger than itself, such as A Q X, the curve P Q traced by P is a hypocycloid to that circle. And it is remarkable that if the tracing circle is exactly half the size of the one in which it rolls, the hypocycloid P Q is a straight line, and is itself the diameter of the large circle, and therefore teeth so described are called radial teeth.

Now suppose A R Y is the circumference of what is called the *geometrical* or *pitch* circle of a wheel which is intended to drive another, and A Q X the pitch circle of the wheel to be driven, which is generally called the 'follower,' but which I think it better to call the *runner*, as followers do not usually run before their driver; then it is easy to see that the arc A P of the tracing circle is equal both to A R and to A Q, and also that the epicycloid is always more convex than the hypocycloid, and therefore that the point P in the tracing circle is always the point of contact between two teeth so traced, and the velocity of the two wheels is always the same as if their pitch circles rolled upon each other without any teeth at all. It is hardly necessary to observe that the teeth of the driver, to act after the line of centres, must be wholly outside its pitch circle, and those of the runner wholly within. The part of a tooth within the pitch circle is generally called its *flank* or *root*, and the part outside is called the *point*, or the *addendum*, and sometimes the *curve*, because the flank is generally made radial, i.e. a hypocycloid described by a circle of half the diameter of the pitch circle. For it is further to be observed that although the points of the driver and the flanks of

the runner must be traced with the same circle, it is not the least necessary that the points and the flanks of the same teeth should be traced with the same circle.

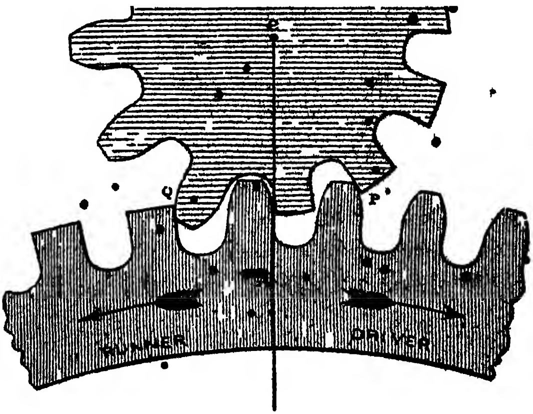
In clockwork the wheels always drive and the pinions run, except the 12 hour wheel in the dial-work, and the winding wheels and pinions if there are any. It can be proved, as you may see in Professor Willis's *Principles of Mechanism*, but the proof is too long to give here, that no pinion of less than 11 leaves (except of a kind which I shall describe presently) can be driven entirely after the line of centres. A pinion of 10 can very nearly; and there is so much difference between the force required to drive pinions of 8 and those of higher numbers, that some spring clocks with Macdowall's escapement which answered perfectly with pinions of 10 or 12, failed with the common pinions of 8, for want of force to drive the two extra wheels in the train. Professor Willis gives the following table of the lowest numbers which will work together with all the action after the line of centres:—

Driver	54	30	24	20	17	15	14	13	12	11	10	9	8	7	6
Runner	11	12	13	14	15	16	17	18	19	21	23	27	35	32	176

The practical inference from this is, that if you use these numbers, or any higher ones, together, the driving teeth require no flanks and the running ones no points: indeed if you mean to prevent any action before the line of centres, the runners obviously must have no points, because if they have they will be geometrically identical with the teeth of a pinion intended to drive the wheel after the line of centres when reversed. Suppose for instance, what is nearly the case in the Westminster

clock, that the great striking wheel at one end of the barrel and the great winding wheel at the other are both of the same size and number of teeth, and that their pinions are also the same; then as the striking wheel always drives, but the winding wheel is always driven by its pinion, the striking pinion and the winding wheel ought to have no points to their teeth, and the sections of the two wheels and pinions would be as in this figure, the right hand representing the

Fig. 46



striking part and the left the winding, and the action being in both cases, you observe, after the line of centres A C, as the arrows indicate.

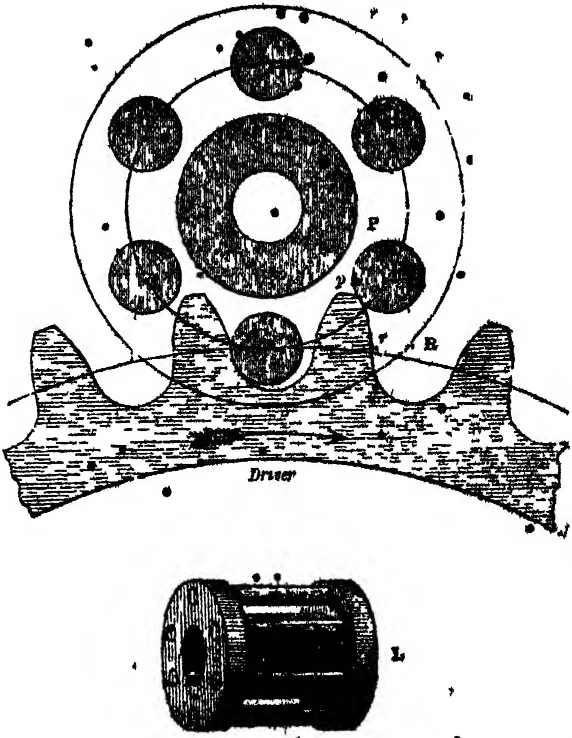
It is evident that the same wheel cannot properly drive two pinions with radial or straight-flanked teeth. Whenever the same wheel has to drive two pinions, the flanks of the pinion teeth and the points of the wheel teeth must be traced with the same circle, and that

circle must not be larger than half the size of the smaller pinion, or else it will make the teeth of that pinion weaker at the roots than even radial teeth are, which are of course narrower at the bottom than the top, and therefore are a weak form, especially in small pinions. A case of this kind occurs in every clock on the patterns I have described at figures 29, 41, and in the Westminster clock, and in short wherever the second wheel in the going train does not turn in an hour, and the dial work is driven independently. In this case, the 40 teeth of the hour wheel (or whatever the number may be) require no points, and must be hypocycloids described by a tracing circle of half the diameter of the other pinion of 10 or 12 which is driven by the great wheel, if the teeth of that pinion are radial.

Lantern pinions. But there is another, perfectly different kind of tooth, which is much better for pinions of small numbers than radial teeth or leaves, viz. what is called a lantern pinion. These two figures of it will show its construction better than any explanation. I believe it is the oldest form of pinion in the world, but it had almost if not quite fallen into disuse in England, though not abroad, when it was restored by Mr. Dent in his turret clocks, about 15 years ago. They work with much less friction than common leaved pinions of low numbers when driven, the run upon them being less and the action wholly after the line of centres, and the shape of the wheel teeth requiring less accuracy to drive them smoothly. They are not however proper for driving, because then of course the action comes all before the line of centres. In some French turret clocks the winding pinions are nevertheless wrongly

made as lanterns, and the pins themselves pivotted instead of rivetted in their sockets so as to turn while

Fig 47.



they are working, which makes the working loose and shaky and the pinion itself very much weaker than when the pins are fast, and saves very little in friction besides.

For the purpose of geometrical construction, we may first consider the pins as being of infinitely small thickness, and then the teeth which drive them would be of

the dotted form P E in fig. 47, being epicycloids traced on the wheel with a circle the full size of the pitch circle of the pinion. Then in order to get the shape of the teeth for pins of the actual size, you must gage off half the breadth of the pin from each side of the tooth, which reduces it to *p r*, and you may leave on just as much point as will keep hold of the departing pin P until another tooth has got well hold of the next pin just as it crosses the line of centres. This operation of reducing the theoretical to the actual tooth is practically equivalent to tracing the tooth with a smaller circle: how much smaller, will depend on the number, *i.e.* on the thickness of the pins, in proportion to the size of the pinion. I find that a lantern of 8 or 10 requires a tooth which fits a leaved pinion of the same number so nearly that I can see no difference in the curves on a pattern as large as 9 inches diameter; and even with 12 the difference is very small; although a theoretical lantern pinion with pins of no thickness requires the same shape of teeth as a radial pinion of twice its size. I have no doubt that a lantern of 8 runs as easily as a leaved pinion of 12, and of course it requires only ⅔ the number of teeth in the wheel, and is also itself stronger, and much less liable to break, both in hardening and in working afterwards.

I may however repeat the caution that cast iron wheels do not work so well with steel pinions, which lanterns necessarily are, as with cast iron, and therefore if the great wheel only is of iron and the smaller ones of brass or gun metal, the pinions should be made of iron or steel accordingly. Also it should be borne in mind that you cannot draw out an arbor with a lantern

pinion endways, by unscrewing the front bush only, and therefore they should not be used where you cannot conveniently get at the back bush to take it off. These pinions are used in all the American clocks and also in the cheap German or 'Dutch' clocks, both of which, it is well known, will go with an amount of dust in their insides which would stop a clock with leaved pinions completely. But the English clockmakers will not use them in small clocks: Mr. Dent attempted it; but as English small clocks are not yet made in factories, as large ones are, and as they are everywhere else in the world, the men who make them up have the power of obstructing every such improvement, and exercise it by immediately charging a higher price for every deviation from the common form, or for everything which they fancy is going to be applied to some new use. The leaved pinions of English house clocks are made out of 'pinion wire,' which is in fact a very long pinion drawn through a hole like wire, and the leaves are turned off to form the arbor and pivots. The American and Dutch clocks prove clearly enough that lantern pinions can be made at least as cheap as others; and if any man of skill, capital, and determination would follow the example of Mr. Hobbs in locks, and set to work to manufacture clocks in a factory of his own, we should soon see this and other improvements made, and the clock trade recovered out of the hands of foreigners, to whom it has been in a great measure sent away by this combination of workmen, who will ruin this and every trade in the kingdom if they are allowed to have their own short-sighted way.

Inasmuch as English clocks are thus made by hand,

and therefore probably no two are exactly alike, it is necessary to have a tool for marking the places where the holes for the pivots of the wheels are to be drilled, to bring them to the proper depth for working. This *depthing tool* is something like two vices framed together parallel to each other, each carrying a thick sliding pin sideways through each of its jaws. These 4 pins have a small hole or 'centre' at the inner end and a point at the outer. The pivots of the pair of wheels to be fitted are put in the 4 centred ends of the pins, and the machine is adjusted by trial till the wheels are felt to work together comfortably. Then the points at the outer ends of each pair of pins indicate the distance of the centres of the wheels, and may be used to mark that distance on the frame-plate. If you cannot get two wheels to work together without shake (so long as they are driven the same way) by any adjustment of their depth, the teeth are wrongly cut in one of the wheels at least, and they have no business to be used.

Bevelled wheels. Everybody who has occasion to use or make bevelled wheels for changing the direction of two arbors, knows that the principle of them is that all the surfaces of the teeth should converge to the point where the axes of the two wheels would meet. Nevertheless in the great majority of such wheels the sides of the teeth do not do so, but converge more rapidly than they ought, so that the teeth have no contact at all except just at their outer edges. The reason of this is that if the sides of two adjacent teeth are cut in the common way with the same cutter, the breadth of the cut is the same throughout, and not narrower at the inside than the outside, and therefore

the teeth evidently taper too much. Fortunately there is seldom much pressure on the bevelled wheels in clocks, and therefore the defect is not very material: but still it is one, and its frequent occurrence is another reason why the bevelled wheels should be large in diameter rather than in thickness; for the larger they are the less pressure there is on the teeth, and the less any inaccuracy of cutting is felt (as it is in wheels of all shapes), and also the less angular motion or shake of the hands and wheels there will be for any given amount of shake in the teeth.

Skew-bevelled wheels. It may be worth while to know that bevelled wheels can be made with oblique teeth, to work with their arbors not in the same plane, provided they have only to work one way; but the friction is very great if they work what may be called the wrong way, and even in the right way the friction is more than in the usual conical wheels. I have never myself seen any clock where it was necessary to resort to this construction, which may be found in books on machinery, and therefore I only mention it in case anybody may have occasion to resort to it.

Cams may be defined as teeth which have to raise a lever or a sliding rod, and not a succession of teeth, and therefore each cam must work up to its end, and drop the lever there, whereas in wheels a second pair of teeth may and always should come into action before the preceding pair have quite separated. The simplest form of cams to raise a lever is that shown in any of the pictures of striking work of house clocks, figs. 26 to 28, viz. a set of pins stuck into the side of a wheel, which catch the lever at some distance from its end and work

up to the end and then let it drop off. This does well enough for very light hammers requiring only a small clock weight, but is just the worst plan that could be invented for large ones. If you take the trouble to draw a wheel with 8 pins in it, each pin acting on the lever through about 36° (leaving the difference between that and 45° for the clearance) you will see that the angular lift of the lever towards the end of its motion is only one-third of what it is at the beginning, and therefore $\frac{2}{3}$ of the clock weight is wasted during part of the lift. And that is by no means all; for if you look at fig. 32 you will see that, as turret clock hammers are usually fixed, the weight of the hammer acts more vertically or requires more force to lift it at the beginning of its motion than at the end; and besides all this, there is the fact which I have several times mentioned, that the loss of power by friction in driving through short levers (which the striking lever is at the beginning of its motion) is very much greater than through long ones with less angular motion. Under all these circumstances it is no wonder that the weight required to make a large clock strike is often three or four times the theoretical 'duty' of the clock, or the equivalent of the hammer × its lift × as many blows as it strikes for once winding; i.e. that $\frac{2}{3}$ or $\frac{3}{4}$ of the force is wasted in bad leverage and friction; whereas in the Westminster striking part little more than $\frac{1}{4}$ of the theoretical duty of the clock weight is lost in friction, leverage, and the necessary clearance or drop for the lever.

The first condition therefore which the striking cams ought to satisfy is they should begin to act at the end

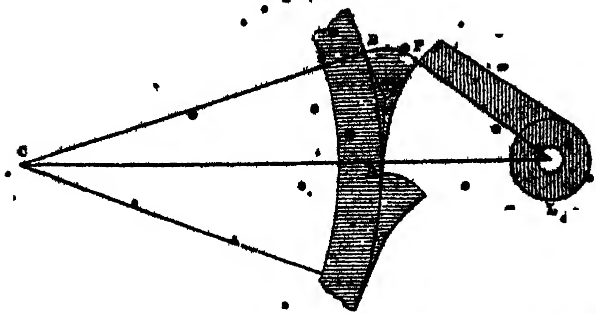
of the lever. It is not necessary that the action should be quite at the end all the way through, provided it is so at the beginning, where the lift is hardest for the clock, and at the end of the action so as to let the lever drop suddenly; for which reason also rollers are worse than half round pins, besides the reasons just now given against using pins at all. The curve which does keep the cam acting on the end of the lever throughout, and as a tangent to itself, without any scraping, is called in mathematics the *tractrix*. If you wish to describe it, the way is this. Set a smooth round board of the size of the cam wheel with stiffish paper pasted over it (to efface the grain of the wood) on a pin through the centre on a horizontal table; and set also on the table, on another pin, a model of the intended lever, with a vertical pencil at its intended point, so as to press upon the paper, the lever being weighted a little. Set the lever on the line of centres and turn the wheel; it will drag the pencil over its surface in a curve which is the *tractrix*, unless it has been disturbed by some inequality of friction between the paper and the pencil, or at the axis of the lever; which is so likely to happen that you cannot safely rely on this construction, unless you find that a good many of the curves so traced agree with each other. It happens however, that there is an epicycloid which agrees with this so nearly that it may be used without sensible error. Suppose r is the radius of the circle which forms the bottom of the cams (*i.e.* their theoretical pitch circle, allowing nothing for clearing the end of the lever) and l the length of the lever. The lever will work as a tangent on its end throughout (without any appreciable error for such

length of cam as is ever wanted) on epicycloidal cams traced with a circle whose diameter $=\sqrt{r^2+rl}-r$. Thus if $r=8$ in. and $l=4$ in. the radius of the tracing circle will $=$ ·9 in. Another advantage of these cams is that you may cut them off at any length, provided only you keep the lever of the proper length; if you alter that you will get scraping friction, and soon wear out either the cams or the lever.

If you prefer having circles to deal with instead of epicycloids, there is another form of cam, which was suggested to me by Mr. Effingham Lawrence (another horological lawyer, like Mr. Bloxam, and all the members but one of that jury in the great Exhibition, both English and foreign), and which acts quite as well as the epicycloid or tractrix, provided you take care not to alter the length of the cam: *i.e.* you must not put more or fewer cams on the wheel than they are designed for, and you must take care that the proper distance of centres of the wheel and lever is preserved. In fig. 48, C A L is the line of centres, and A B the space for one cam on their pitch circle; by which I mean the space occupied in lifting, for you see a little space is left below the line of centres before the next cam begins, to prevent the lever dropping onto the cam itself, which shakes the clock most injuriously. A P is the arc of the lever. Draw A T, which is a tangent to the two circles at A, and B T a tangent to the cam circle at B. That point T will also evidently be the place where a tangent to the circle A P at P would meet the others; or in other words, T is the centre of a circle B P, to which the lever itself will be a tangent both at the beginning and the end of the lift, although the contact

will be a little way from the end during some intermediate part of the action.* The backs of the cams must be cut out a little deeper than down to the pitch

Fig. [illegible]



circle, to let the lever drop freely; and it is important to remember that the end of the lever itself should not be left sharp, or it will cut off the ends of the cams if they are not very hard, and perhaps break them if they are. I know that by experience.

It does not occur to me that cams can ever be required in clock-work for lifting a vertical rod sliding like a stamper. If any such case should occur, involutes of the wheel circle would be the right shape for the cams.* There may also be cases where it would be worth while to pull down a long striking rod by pins in the wheel catching a square hook at the end of the rod, and dragging it on with a little sideway motion until it is struck off the pins by a horizontal stop: this would avoid all the lever work and all friction except at the striking off of the hook.

* This is no exception to the epicycloidal rule, for an involute is in fact an epicycloid traced by a circle of infinite size, i.e., by a straight line.

Oil for clocks. I believe it is now generally understood that sweet oil is the worst that can be used for machinery, large or small, except when it is purified in certain ways not known to the public; and then it is too expensive for use in large or common clocks. For them purified sperm oil, such as is now made wholesale for other machinery, is quite good enough. Common neat's-foot oil may also be purified into a very good oil, which will hardly freeze here. It can only be done in cold weather; it should be shaken in a bottle with water until it becomes a thick white soup, and then left to stand, and the fine oil that gradually comes to the top skimmed off, taking care to get none of the thick. If it is done in a warm temperature, oil appears at the top as fine, which has no business there, and will not remain fine in cold weather. Mr. White of Fredericton sent me a small bottle of oil a few years ago which he says does not freeze even in their cold of $-40°$, which is enough to freeze mercury. I do not know how it is made.

It must be remembered that oil has always a tendency to run away from small points of teeth, the ends of pins, &c., to the thicker parts of the wheel. In some French clocks the teeth of the dead scapewheel are accordingly made with a kind of lump at the end; but this wastes more space in the clearance or drop, and it is never done in English clocks, so far as I have seen; nor do I know anything that will answer—except putting on fresh oil when it is wanted. As I have said before, dirty oil should always be cleaned off before putting fresh oil on.

WATCHES AND CHRONOMETERS.

The early history of watches seems to be quite as obscure as that of clocks; if we concede the name of a watch to any small portable horological machine with a spring for its moving force and a vibrating balance for a pendulum. But a watch without a balance-spring differs from a watch with one as much as De Vick's clock with a mere fly-wheel balance differs from a pendulum clock; and it is singular that the balance spring and the pendulum, the two great elements of horological accuracy, are not only almost coeval, but the invention is fought for by the same claimants, or two of them at any rate, Huygens and Dr. Hooke. According to *Rees's Cyclopædia*, Dr. Hooke is proved at any rate to have been the first publisher of the discovery, 200 years ago, and therefore he has the best claim to be regarded by the world as the inventor. He enunciated the principle of the discovery of the isochronism of springs in the short sentence *Ut tensio sic vis*: or, the force varies as the degree of tension: which rule however we shall see presently has two rather curious exceptions.

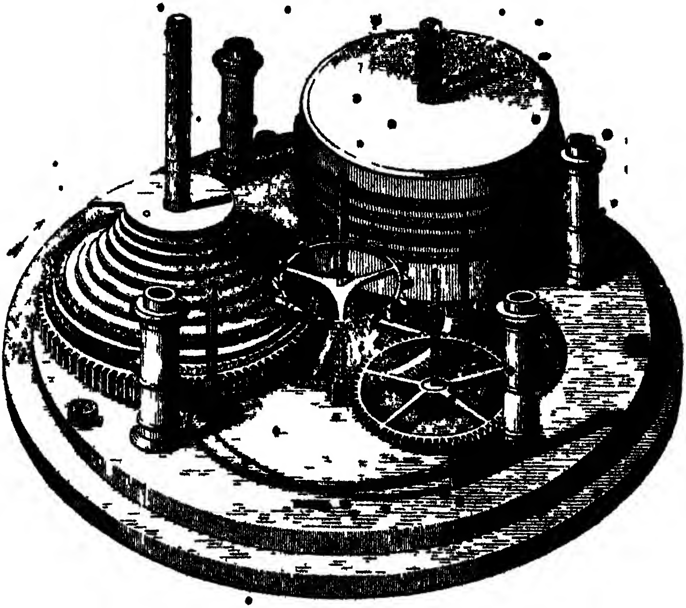
The main-spring of a watch is a thin ribbon of steel coiled up in a barrel round a strong spindle to which one end of the spring is fixed, the other end being fixed to the barrel. When it is wound up the coils lie close together upon the spindle or arbor, and as the spring runs down the coils separate from the arbor and lie close to the barrel. The simplest construction, still used in

most of the foreign watches, is for the barrel arbor to be the winding arbor, having a ratchet wheel squared on to it, held by a click on the frame or plate of the watch, and the great wheel is on the barrel itself; and in this case, as I explained at p. 154 with reference to spring clocks, no temporary maintaining power or 'going barrel' is required to keep the watch going while you are winding it up. But it is obvious that as the force of the spring is greater when it is tightly wound up than when it is loose, the force of the train will be very far from constant throughout the day, although that may not affect the going of the watch from one day to another. But on the other hand, there is found to be a very singular exception to that rule of Dr. Hooke's stated just now, inasmuch as there is a position of the spring coiled in a barrel in this way, in which there is no material variation of its force for a few turns. And certainly some of the foreign watches made in this way go well enough for ordinary purposes, and one reason why they can be made so small is that they do not contain another piece of machinery which is added in all the best watches, and indeed in common English watches to equalise the force, called the—

Fusee. That piece is a hollow-sided cone, which you see in this picture of a chronometer or English watch movement, with a chain round it and the barrel, and the great wheel is no longer on the barrel, but on this conical piece called the fusee. When the spring is wound up and its force is greatest, the chain acts on the small end of the fusee and therefore with the smallest leverage, and as the spring unwinds, the chain acts on a thicker part of the fusee, and it can be, and in

good watches is, so adjusted that the force on the train and escapement is constant. It was suggested by Mudge, the inventor of the lever escapement in the form now

Fig 49.



used in 99 out of 100 English watches, that the usual position of the chain is wrong: and so it is; for you see in fig. 49 that it acts on the opposite side of the fusee to the centre pinion, and consequently the pressure and friction on the fusee pivots (which are necessarily large ones) is the *sum* of the force of the spring on the fusee and of the great wheel on the pinion; whereas if the spring acted on the same side as the pinion, it would only be the *difference*. I confess I know no reason why

the common arrangement should be adhered to, except that it is the common one, which is generally considered reason enough for anything bad.

The train of wheels in a watch is much the same as in a clock, except that the scapewheel is not the wheel which turns in a minute and carries the second-hand, but is another faster wheel. In a pocket lever watch the balance generally beats in $\frac{2}{5}$ of a second, and in a chronometer either in that time or in $\frac{1}{4}$ sec. The scapewheel generally has 15 teeth, and therefore turns in 6 seconds or something near it. In a good lever watch the pinions are generally 7, 8, 8, 10, and the wheels 63, 60, 64, 75; in a pocket chronometer the pinions are 8, 10, 10, 12 and the wheels 80, 75, 80, 72; in box or marine chronometers the numbers are still higher, the pinions being 10, 10, 12, 14, and the wheels 80, 80, 90, 90. Box chronometers are generally made to go rather more than 2 days, though they are wound up every day, and they have a small hand on a separate circle in the dial indicating how far the barrel has run down. In these watch trains it must be observed that where a slow wheel has fewer teeth than a quick one, of course the teeth must be larger, or the wheels could not be put into the frame, as observed at page 27. I think no pinion so low as 7 should be admitted, and I cannot understand why 9 should be a prohibited number in clocks and watches, as it seems to be except in lantern pinions for clocks, which are made to order and not cut out of pinion-wire.

Winding Stops. A watch, or a spring clock, with a fusee is stopped from being overwound by a long tooth which you see in fig. 49 sticking out from the

thin end of the fusee. There is a spring lever with a hook fixed to the frame with a little play on its pivot, so that when the chain comes to that end, or the fusee is full, it pushes the lever just far enough for its hook to catch the tooth, and so stops the winding. In foreign watches without a fusee, a thing called the *Geneva stop* is used: it consists of a small wheel on the barrel-arbor, with only one tooth in it and the rest of the circumference filled up blank; this tooth works into the teeth of another loose wheel set on the watch frame, which has only as many teeth as the number of turns that the barrel has to make in winding or going, and has also a blank space in its circumference. The one-toothed wheel turns the loose wheel through the space of one tooth for every turn of the barrel, and when those teeth are all past, the one-tooth jams against the blank in the loose wheel and lets the barrel turn no more, and so stops the winding. Of course the same thing might be put on a fusee arbor, but the spring stop is preferred.

The dial wheels of a watch are more like those of a turret clock than of a house clock in the division of the numbers of the teeth, as there is no occasion for the intermediate wheel and pinion, called N in figs. 22, 27, to turn in an hour, as it does in house clocks to discharge the striking, and even in silent clocks for uniformity. The hand sockets are also only held on by friction without any spring. In other respects the train of a watch is substantially the same as that of a small clock until we reach the escapement, except that there is one more wheel in the train, for the reason given just now. The dial pinions in a good watch are 12 and

14, and the wheels 42 and 48; in a box chronometer they are 14 and 18, and 54 and 56.

The escapement is the only place in which there is a fundamental difference between a watch and a clock. I shall describe the principal watch escapements presently, after we have considered the principle of the balance, which is common to them all. The balance wheel resembles a pendulum in vibrating and in letting a tooth of the scapewheel escape somehow at every vibration, as in the earliest clocks before pendulums were invented. But considering that the pendulum moves by gravity, through an arc of only 4° or 5° with a variation never amounting to 30′ in a good clock, while the balance swings independently of gravity through an arc of sometimes 400° and sometimes no more than 100°, it is evident that a watch escapement must be a very different thing from that of a clock. When I say that a balance is independent of gravity, you must remember the distinction between mere mass, which we denoted by the letter M in treating of pendulum, and mass acting as a force by means of its weight, *i. e.*, by the earth's attraction, which we called M*g*. The mass and the moment of inertia of a balance have quite as much to do with its motion as they have in a pendulum, but the force which makes it vibrate or return from the impulse given in the escapement, is not gravity (which must be entirely excluded, or the 'balance' is not a balance, and will not keep the same time in different positions of the watch), but a thin spiral spring, of which one end is fixed to the balance and the other to the watch frame. This is popularly called the *hair-spring*. It was to this spring that Hooke's law of

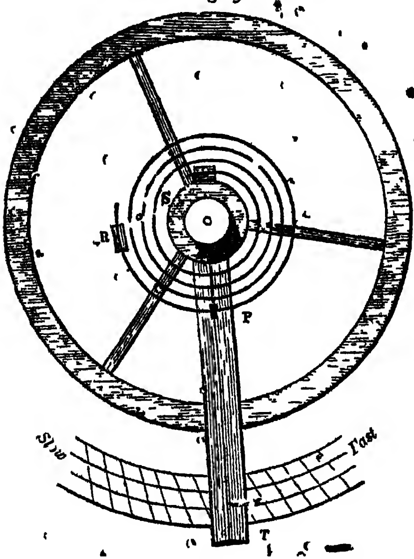
the force varying as the tension or space moved through (which always implies isochronism) was meant to apply, and does apply pretty generally; but not invariably, because it is found that not every length of a given spiral spring is quite isochronous, but only certain lengths, which I suppose can only be determined by experiment.

The time of vibration therefore depends on the moment of inertia of the balance directly and the force of the balance spring inversely; and in a given spring the force varies inversely as the length. Consequently you can quicken the vibration either by reducing the moment of inertia or the size of the balance, or by shortening the effective length of the spring. The latter method is used in all common watches, and the former in chronometers and watches in which extreme accuracy is aimed at.

Regulation of a common watch, to make it go faster or slower, is done by a lever or index S P T (fig. 50), which turns on a ring set on the watch plate (through which the *staff* or arbor of the balance has to pass from the inside to the outside of the watch frame), and it has two small pins at P which embrace the spring, one end of the spring being fixed to the frame at R and the other end to the balance at S. It is evident that as you turn the regulator to the right you shorten the length of the acting part of the spring and so make the vibrations faster, and if you move it to the left, slower. If the regulator has been moved as far toward *fast* as it can go and the watch still loses, the spring must be taken up altogether at R; and then in order that the balance may still be in the middle position of the escapement when the spring is

neutral, the piece S by which it is attached to the balance is itself a ring which fits tightly round the staff and can be moved when the balance is taken out, to alter the position and length of the spring.

Fig. 50.



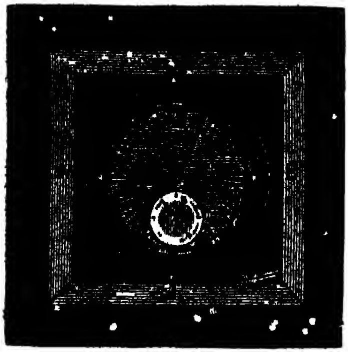
It must have occurred to everybody who has had to regulate a good watch for very small errors that there is a want of some better method than the common one both for moving the regulator and for seeing how much you move it. The best undoubtedly is a tangent screw movement, the screw being turnable by the watch key, and I am surprised that expensive watches are not always furnished with this simple addition. Another suggested by Mr. Dent is shown in fig. 50. Instead of being made with a point, the index has fine bevelled edges lying quite over the index plate, which is to be made with oblique divisions and two or three cross lines, like the scale generally engraved on a dividing rule: this enables the eye to measure much smaller divisions than could be either seen or cut upon a degree plate of the common form.

This mode of regulating by shortening the effective length of the spring is not accurate enough for chronometers for another reason, viz. that all lengths of the spring are not quite isochronous for different arcs of vibration, and therefore if you have got the spring adjusted for an isochronous length, it will become unisochronous if you shorten it a little; and moreover a spring moving in that way, partly held fast at the ends and passing loosely through curb pins at P, is not so steady as one held fast only at the ends. Chronometer balances are therefore regulated by *timing-screws*, which are screws with heavy heads set in the rim of the balance: screwing them in of course diminishes the moment of inertia and quickens the balance, and vice versâ. In chronometers also the spring is generally made in a cylindrical spiral and not a flat one. Some chronometer makers have doubted whether there is any advantage in the cylindrical form, but it is now almost universally adopted, and therefore I suppose the balance of experience is in favour of it. But the quality of the spring is probably of more importance than its form. A medal of the highest class was awarded in the 1851 Exhibition to M. Lutz of Geneva for some balance springs, made by a secret method, which bore being pulled out nearly straight and laid on a hot plate without suffering any change of form, which was not the case with any others which were then submitted to us.

Timing for position. As a watch sometimes lies flat on a table, and sometimes vertical, and not always in the same position in your pocket, it is necessary that the balance should keep the same time in all positions,

both horizontal, and with either iii. vi. ix. or xii. upwards. With a heavy balance it is impossible to get the same arc of vibration when the watch is vertical and horizontal, because the friction of the pivots is much greater when they are acting on their sides than on the point of one of them. If you take a small chimney-piece clock with a balance and hold it sideways so that the balance becomes vertical and its staff horizontal, you will see the vibration diminish very much, and then the least want of isochronism in the spring will set the rate wrong. Marine chronometers, which are only very large watches, are therefore always set horizontally in a box, in *gimbals*, as in this drawing, which keep the watch horizontal, even when the box is tilted by the ship: if the box is tilted at E or W, it turns on the outer pivots N S of the gimbal ring, and if the N or S side is tilted, then the box and ring together turn on the inner pivots at W and E leaving the watch steady. The level of the pivots should be only just enough above the centre of gravity of the watch to make it keep its level, for if the c. g. is much below the points of support the body will swing when they are moved.

Fig. 51.



Ship time-pieces. There is another kind of ship-clocks made to hang against a wall, not pretending to

the accuracy of chronometers, but a very neat and convenient and cheap form of time-piece for other places as well as ships. They are a large 8-day lever watch with the balance staff and the scapewheel arbor vertical, and therefore the third wheel in the train a *contrate* or crown-wheel as in fig. 6. Like other things, they are of very different qualities with the same external aspect. They do not work well without a fusee, though many of them are made so for cheapness, and the contrate wheel arbor ought to have an end-stop to the pivot which tends to push away from the scape-wheel pinion and work upon its shoulders, and of course the two vertical arbors ought still more to have their lower pivots resting on stops either of hard steel or jewels, to take the weight and friction off their shoulders. End stops are sometimes put to the horizontal arbors of highly finished clocks; but as there is no end pressure on them, I think it is hardly worth while there, though it is in the two cases I have just mentioned. Chimney-piece clocks with balances (the only ones which house-maids will allow to go, unless they are too heavy to move) ought always to have them compensated, for otherwise the great changes of temperature to which they are exposed will make it impossible for them to go right, as I shall now explain.

COMPENSATION OF BALANCES.

Watch balances, or rather the springs on which their time depends, vary much more with heat and cold than pendulums, and therefore compensation is still more essential if you expect great accuracy of rate; and if it

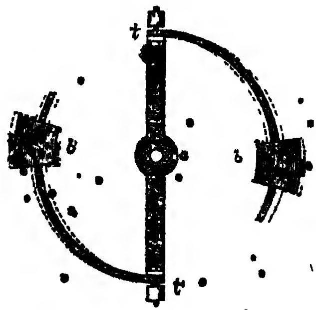
were not that watches are kept at a pretty even temperature during the day by near contact with men's bodies, their variations in hot and cold weather would be enormous: women's watches being generally worn loose, go worse than men's for that reason. A small portable clock with a balance uncompensated goes worse than the commonest clock with a pendulum. The balance itself also expands a little with heat just as a pendulum does, but the effect of that is small compared with the variation of the force of the spring. It appears from some experiments made by Berthoud in 1773, and others by Mr. Dent communicated to the British Association in 1833, which nearly agreed, that the loss of time due to expansion of the balance for a rise of temperature from 32° to 100° is not $\frac{1}{4}$ of that due to the loss of elasticity and elongation of the spring, and that the two together amount to no less than $6\frac{1}{2}$ minutes a day; and a varia- of 33° would produce a variation of an hour in 3 weeks; whereas we saw that a common iron wire pendulum would only lose 10 sec. a day for such an increase of heat, and a wooden one not more than $1\frac{1}{2}$ seconds, if so much.

The first watch compensation was made by Harrison, who has been mentioned several times already as the inventor of various horological improvements; and he received the first parliamentary reward for improvements in chronometers with a view to finding longitude at sea. His method is quite disused now, and indeed he was himself dissatisfied with it, and suggested that the compensation ought to be done in the balance and not by any contrivance for altering the effective length of the spring, which was the principle of his own and all the

early compensations. For this purpose he put the curb pins (see fig. 50) on a compound bar, of which one side was made of brass and the other of steel; as the brass expands more than the steel the bar necessarily bends to the steel side when the heat increases, and thus the curb pins were moved along the spring, just as they are by the common regulator. It is not necessary to dwell on any of the various modifications of this plan, as they are all now abandoned for the balance of compound bars, which appears to have been first made, as well as a mercurial compensation balance, by Julien le Roy, a celebrated French clockmaker, but afterwards much improved by the first Arnold, Earnshaw, and various other English makers. A great variety of these contrivances may be found in *Rees's Cyclopædia* by those who are curious about them.

The plan which is now always used, with some modifications in certain cases, as I shall explain afterwards, is exhibited in this drawing: *t a t′* is the main bar of the balance, with the timing screws for regulation at the ends; and *t b*, *t′ b′* are two compound bars, of which the outside is brass and the inside steel, carrying weights *b b′* which may be screwed on at different places. As the heat increases, those bars with their weights bend inwards and diminish the moment of inertia of the balance. The only secure way of making these balances

Fig. 52.



is to cut them out of a solid steel disc round which melted brass is run. This plan of uniting the metals was introduced by Earnshaw, it appears, besides various other improvements in the construction of chronometers, in which very little alteration has been since made in 80 years. The principal expense of a really compensated balance is in the time required for adjusting it, which can only be done by trial. Many watches are sold with balances only constructed for compensation but never adjusted, and therefore under or over compensated, or with no regularity in the action of the compensation; and some still worse, with a mere sham compensation, resembling a compensated balance only in appearance, sometimes not even cut through.

The chronometrical thermometer is simply a watch with a balance compensated the wrong way, *i.e.* with the brass inside and the steel outside, so as to increase the retardation from heat and the acceleration from cold. The use of it is to measure the quantity of heat or cold received during any given period without recording the actual degree of heat or cold at any particular time. It is therefore used at the Greenwich Observatory for trying the rates of compensated chronometers under great variations of temperature.

Secondary compensation. When chronometers had been brought to great perfection, so as to go with scarcely any sensible variation of rate while they were kept within moderate limits of temperature, it was observed that they always lost if the temperature either rose or fell beyond those limits; and on the other hand, if the compensation was adjusted for two extreme temperatures, then the watch always gained at mean

ones. I believe it has never been disputed that Mr. Dent was the first person to explain the cause of this error, in the *Nautical Magazine* in 1833; and he gave the following illustration of it: The diminution of force in the spring proceeds uniformly in proportion to the increase of heat, and may therefore be represented by a straight line inclined at some angle to another straight line which is divided into degrees of temperature. But the inertia of a compound balance such as I have described cannot be made to decrease quite as fast as the heat increases; and therefore its rate of variation can only be represented by a curve, and can therefore only coincide with the straight line representing the variation of force of the spring in two points, either the two extremes, or two means, or one mean and one extreme point: in other words, the compensation can only be exact for some two temperatures for which you may choose to adjust it.

The same thing may be shown mathematically as follows: Let r be the distance of the compensation weights from the staff or axis of the balance, and we may call them both together M, and for this purpose we have nothing to do with the rest of the balance. Let dr be the increase of distance of the weights for some given decrease of heat. Then the new moment of inertia of the balance will be $M(r^2 + 2r\,dr + dr^2)$, and the ratio of the new inertia to the old will be $1 + \frac{2\,dr}{r} + \left(\frac{dr}{r}\right)^2$; and now the term $\left(\frac{dr}{r}\right)^2$ is too large to be disregarded as it may be in the similar formula for pendulums, because dr must be much larger in proportion to r than it is in a pendulum, as we have

been already. Again, the ratio of the moment of inertia for an equal increase of heat, to its moment of inertia in the middle state, will be $1 - \frac{2\,dr}{r} + \left(\frac{dr}{r}\right)^2$, assuming that equal successive increments of heat produce equal variations of r, which however is not quite the case as it is in pendulums. Consequently the increase of moment of inertia for a given rise of temperature is less than its decrease for an equal fall by $2\left(\frac{dr}{r}\right)^2$, or the compensation fails to that extent in one of the three states of cold, middle, or hot temperature.

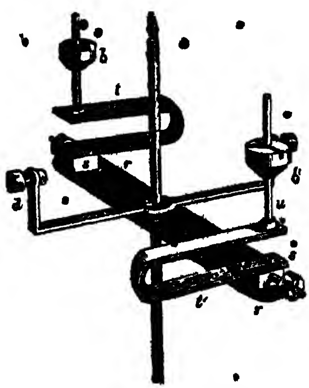
The correction of this error is called the secondary or auxiliary compensation, and it is the point to which I think every chronometer invention for the last twenty-five years has been directed, chiefly because the chronometers are now exposed to such extreme and unnatural variations of temperature in the Greenwich trials—nearly as much as 100°, that the attention of the makers seems to be withdrawn from everything else; and every year's tables display an increased number of contrivances for this purpose, though by no means an increased accuracy in the recorded rates of the best of them.

Eiffe's compensation balance was the first invention for this purpose which was disclosed; and a reward of 300*l.* was therefore given him by the Admiralty on the recommendation of the Astronomer Royal. At the very time while this invention was under trial at Greenwich, Mr. Molineux took out a patent for one precisely similar; which is only one of the usual proofs that when the time is ripe for an invention, it is almost

sure to be made by several people at once, of whom one gets rewarded—or suffers, by a patent. Mr. Eiffe described several methods for effecting the secondary compensation: the one which he chiefly relied on, and which has been followed by some other makers, is a balance in which the compensation bar, or a screw in it, is made to reach another in the form of a spring with a small weight upon it, when it has bent inwards to a certain extent, and it carries that other with it, so as to diminish the moment of inertia still more than the single compound bar. It seems an obvious objection to this, that it is discontinuous, *i.e.*, that the secondary compensation comes into action suddenly at one change of temperature only. Nevertheless it appears to answer as well as or better than many others which are free from that objection.

Dent's balance. The next in point of date was Mr. Dent's, of which also there were several forms: this (in fig. 53) is the one which he proposed as the best in his pamphlet on the subject. The flat cross-bar *r r′* is itself a compensation bar with the brass below and the steel above, so that if the compensation weights *b b′* were set upon upright stems from the bar they would be bent in towards the axis when the heat increases. But they are in fact set upon some other bent

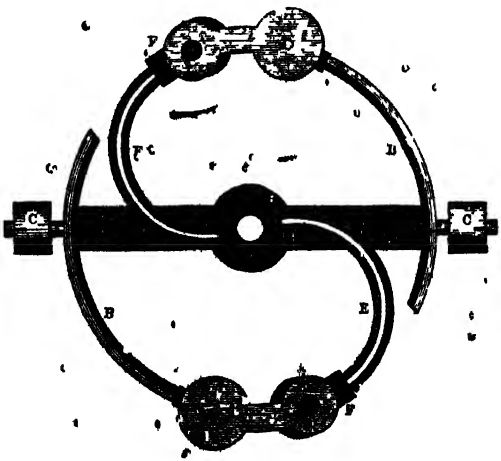
Fig. 53.



compensation bars st, st^1, of which the brass is inside the bend, and consequently the weights approach the axis more than if they were set on stems of fixed length; and as they can be set anywhere on the stems the compensation is thus adjustable. The reason why the bent bars stand outwards across the principal bar is to leave room for the balance spring, which is attached to the smaller cross-bar *d* shown in fig. 53, in which the spring is omitted to avoid confusion. This compensation has the advantage of being continuous.

Loseby's balance. The only other secondary compensation of which a description has been published, so far as I know, is Mr. Loseby's, who has altered the

Fig 54.



mercurial compensation of Le Roy into this form. D D are the weights on the usual compound bars B B, for the primary or principal compensation. Besides

these there are two small bent thermometers with the bulbs at F, and the tubes at E, into which the mercury runs as the heat increases, and so more of the weight of the balance is carried inwards than is due to the mere bending of the primary bars. The tubes are sealed with a little air included. C C are the usual timing screws independent of the compensation. The action here is equally continuous with Mr. Dent's, and Mr. Loseby's chronometers generally got a very high place in the Greenwich lists during the seven years in which he sent them there; and he would have done wisely to be content with that success. But it appears from parliamentary papers that he has applied no less than four times for a reward for this invention, and the Astronomer Royal has four times reported against his claim, on the ground that his balance was neither the first to do what was wanted, nor was proved to be the best. Mr. Loseby then sent to the Admiralty a long memorial, containing a comparison of the rates of his chronometers with others in the Greenwich lists for 5 years, to prove that his was the best; and the last horological paper to which old Mr. Dent put his hand before his death was a counter-statement, showing that a proper analysis of those very trials exhibited Mr. Loseby's compensation as decidedly inferior to Mr. Dent's own, and not at all superior to Mr. Eiffe's or several others of which the constructions were not disclosed.

After his death the controversy was carried on in the Society of Arts' Journal by Mr. Loseby and me, as he had assumed that I wrote Mr. Dent's paper for him, and I extended the analysis to the whole seven years

during which Mr. Loseby's chronometers were at Greenwich, and with the same result. The nature of the analysis is simple enough, viz. this: If you divide the 6 months of published rates in each year into 3 periods, one containing all the coldest weeks, another all the hottest, and another the mean temperature weeks—and whether you make the division into equal periods, or into two periods of 6 weeks of extreme temperatures and 13 or 14 of mean, or make it just where the register shows that the greatest breaks of temperature actually occurred,—the result is always the same, that Mr. Loseby's compensation was the most successful in only one of the seven years, three other makers' each once, and Mr. Dent's three times. The Astronomer Royal's opinion was therefore clearly right in rejecting Mr. Loseby's claim to a public reward, whatever may have been his personal skill in preparing a single chronometer for trial in a year, and so on the whole getting a high place in the list.

Dent's prismatic balance. This was invented by the first Mr. Dent shortly before his death, and improved by the second, for the purpose of effecting the primary and secondary compensation together, or a sufficiently near approximation to it, by a simpler construction than any of the others. The steel part of the balance is the usual flat bar; but the brass is an obtuse-angled bent prism. This invention was founded on the fact that a bar of that form bends more easily from the angle than towards it, and therefore the compound bar bends in more easily and farther than it does outwards, for equal degrees of heat. It has the

Fig. 55.

advantage of making the balance stronger also. It was not supposed that this would make the secondary compensation complete for the extreme temperatures of the annual Greenwich trials; but some of these chronometers have been bought by the Admiralty after trial there; and there seems no doubt that this is better than the common flat bar compensation.

Glass balance springs. These were suggested by Berthoud, but have been very little used. The rate of a chronometer with a glass spring, which Mr. Dent sent to Greenwich some years ago, was very good; and they have the advantage of varying so much less than steel or any other metal in elasticity that they require very little compensation of the balance. I do not know why they have not been more used, unless it be from the fear of breaking them when anything is done to the watch. It appears that with them, as with steel springs, the watch always gains after a new spring has gone a few months, as if it acquired more elasticity by working; and this is analogous to what takes place in bells, which always become more sonorous, *i.e.* more elastic, after a few months ringing.

Greenwich trials. When the rates of some chronometers were returned to Greenwich after one of the Arctic expeditions, the Astronomer Royal reported that they had been *kept so warm* that they afforded no test of the relative value of the different modes of compensation employed in them. I think it might also have been inferred from that fact that the trials at home in such unnatural variations of temperature are only calculated to test a single and comparatively immaterial quality of the chronometers, and to frighten

away from public trial every invention for the general improvement of the instrument in other respects. Any nautical man who wants chronometers for real use would rather have one that would not vary a second a week in such temperatures as it is likely to be exposed to in any voyage in a ship's cabin, than one which may possibly go better than it at some extreme and improbable variation of temperature, but worse in all ordinary and probable variations.

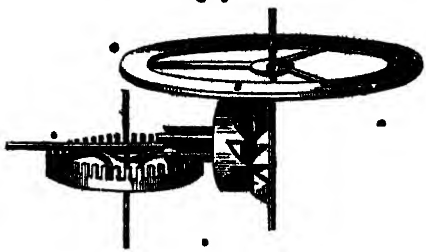
It ought to be understood better than it generally is, that the best chronometers are by no means equal in steadiness of rate to a good astronomical clock, or even to many turret clocks such as I have described. There are indeed records of a few chronometers of singular excellence which have equalled a good clock rate (before the days of violent temperature experiments), such as one by Mr. Dent, of which the daily rate never varied more than ·54 sec., and another by Mr. C. Frodsham with an almost equally small variation of ·57 sec. during the time of trial at Greenwich. But it must be remembered first, that even these are variations of *daily rate*, and not of actual time, and moreover such chronometers as these are much too rare to affect the general fact of the inferiority of chronometers to good clocks.

WATCH ESCAPEMENTS.

There is a greater variety of escapements which may all be said to be in use in watches than there is in clocks, omitting in both cases merely fancy ones of which only a few specimens have been made rather for show than for use, and which I do not think it worth while to describe, either for clocks or watches.

Vertical escapement. The original watch escapement, which has remained in use for about two centuries, but is now going out, exactly corresponds to the old crown-wheel escapement in clocks described at p. 34. This figure (56) shows the mode of arranging it in

Fig. 56



a watch. There are in fact two crown wheels in it, for the wheel with its arbor vertical, the minute wheel of the train, is one, and the scapewheel itself is another. The plain rimmed wheel is the balance. It has all the properties of the recoil escapements in clocks, and is very inferior in accuracy to any of the others, and now has hardly the advantage even of cheapness over the lever, which is the standard English watch escapement.

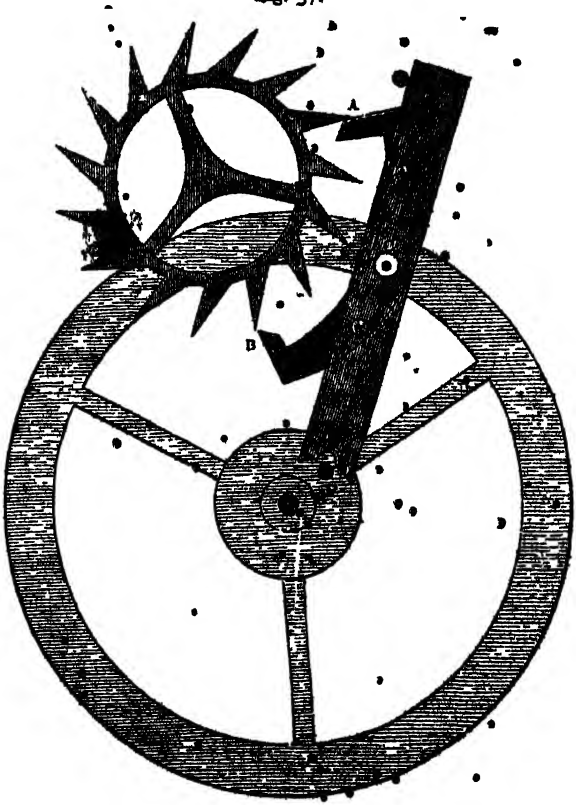
Lever escapement. This in its original form was invented by Berthoud about 100 years ago, and according to the picture of it in Rees's Cyclopædia it is identical in all but the position of some of the parts with the *rack-lever escapement*, of which Litherland of Liverpool used to be the great maker: the first watch I ever had was one of that kind. If you suppose the crutch of the dead escapement of a clock to end in a piece of a wheel, of radius equal to the crutch, and working into a pinion set on the arbor of

a balance, that is the rack-lever escapement. The objections to it are the friction of the rack, *i.e.* of the wheel and pinion, and the dead friction on the pallets; and that was almost entirely got rid of by the modification of it which was invented by Mudge about thirty years afterwards, and which used to be called the *detached lever*, but is now generally called the lever escapement simply, since the rack has gone out of use; and the term 'detached' has been applied to another class of escapements. It is a curious fact in the history of watchmaking, that a parliamentary committee in 1793 thought fit to award to this Mr. Mudge (or his son for him) 3000*l.*, the same sum as Arnold and Earnshaw had had from the Board of Longitude, in opposition to the opinion of that Board, for a chronometer escapement which was not worth one farthing, and indeed turned out worth a good deal less than nothing to his son who spent a considerable sum in making them. However he well deserved his 3000*l.* for the invention of this lever escapement, of which ten times more are now made in England than of all the other escapements together, and which is almost equal to the best in accuracy and steadiness of performance. The following is the construction of it.

The scapewheel and pallets are precisely those of a clock dead escapement; but the pallets A B are set on a lever which turns on their arbor C and has a notch at the end, into which a pin P in a small disc on the verge of the balance works, being in fact a single tooth of the old rack lever pinion. The teeth only just lock on the dead part of the pallets, and the pin and the

notch are so arranged that as soon as the escape has taken place the pin slips out of the notch, and so the balance is detached from the lever during the remainder

Fig. 57.



of its swing. When it comes back again the pin re-enters the notch, moves the lever just enough to send the tooth onto the impulse face of the pallets, and then the scapewheel acts on the lever and balance until

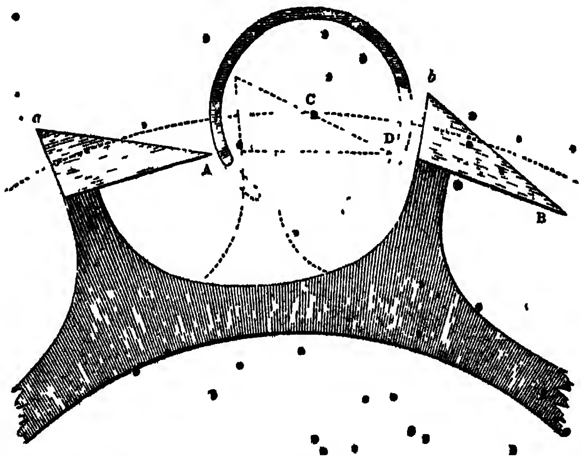
that tooth has escaped and another tooth has dropped onto the dead face of the other pallet, when the pin passes out of the notch in the other direction and the balance is again free. The dead faces have a little recoil the wrong way, to prevent the risk of the teeth slipping off while the balance is free; and besides that, there is another pin S on the lever, which moves through a notch in the balance disc at the same time that P moves through the lever notch: S has no actual contact, but it is there to prevent the lever from shaking back and making a false escape while the balance is free. The pallets are always jewelled except in very cheap watches, and the staff or verge of the balance ought always to have jewelled pivot holes, and in good watches the staff of the lever also has.

Macdowall's single-pin escapement (p. 104) was applied to some watches exactly in the same way. They went very well, but the extra expense of making them was not found worth incurring.

Horizontal or cylinder escapement. It seems strange that Graham, the inventor of the dead escapement, should not have been the author of its adaptation to watches, and should have invented instead a very different one, in appearance at least, which is now almost as universally used in foreign watches as the lever, which you see originally came from France, is in English ones. The verge of the balance is expanded into a comparatively large hollow cylinder in the middle, large enough to hold both a tooth of the scape-wheel and a short stem on which each tooth stands; and about 150° also of the side of the cylinder is cut away, leaving the shaded portion A B in this drawing; in which

the tooth Bb has just escaped, giving the impulse to the balance by its oblique face acting on the edge of the cylinder as it passes out. The point of the next tooth Aa then falls on the outside of the cylinder, just as a tooth in a clock escapement falls on the dead face of

Fig. 58.[1]



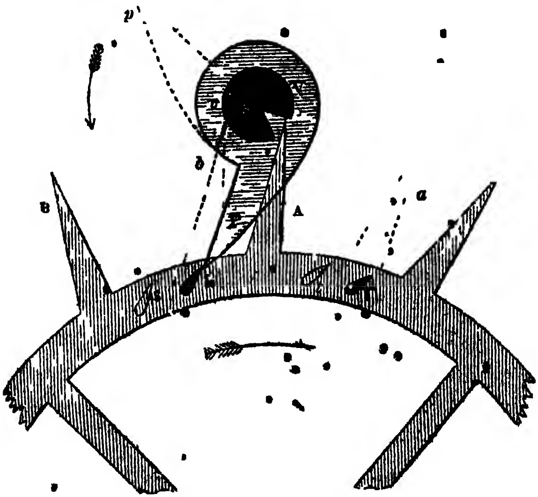
the pallets, and it rests there till the balance returns, and then the outside of that tooth begins to give the impulse until it escapes into the inside of the cylinder and is stopped there as at D, till the balance returns again. The inferiority of this to the lever escapement is evident, inasmuch as the balance is always subject to the friction and pressure of the teeth; and moreover if the staff of the balance gets broken by a fall it is expensive to replace with a new one, which it is not in the lever. In the best watches the cylinder is made of a ruby, and the wheel is generally made of steel, instead of brass as in the other escapements.

There is a French escapement rather like this, called the *virgule escapement*, in which the teeth are in the plane of the wheel as usual, with small pins rising from them near the points, which act on a hollow cylinder, smaller than in the horizontal escapement. At one beat of the balance a pin only passes from the outside to the inside of the cylinder without giving any impulse. At the other beat the emerging tooth acts upon a long impulse face or pallet added to the cylinder and gives the impulse. I believe they are very little made. Most of the foreign watches have the horizontal escapement.

Duplex escapement. This is probably so called because the scapewheel has two sets of teeth, one for the locking and the other for the impulse. The inventor of it is not known. Its action is peculiar and requires some attention to understand it. It is even more distinctly than the last, a single beat escapement, for the scapewheel only moves sensibly at every other beat, *i.e.* at every vibration of the balance in one direction only: not that this makes any difference in the time of revolution of the scapewheel, because in all double beat escapements only half a tooth-space passes the pallets at each beat, whereas in the single beat escapements a whole space passes, or one tooth runs immediately into the place occupied by the previous one: the effect of which is that in a duplex or a chronometer escapement the scapewheel almost looks as if it did not move at all. V*v* is the verge of the balance, which is made of a ruby and has a nick in it through which the long teeth of the scapewheel can pass: one of them is represented as just escaping, and at the same moment one of the impulse pins S is just

ready to act upon the tooth or pallet P on the verge, and so to give the impulse to the balance. By the time S has got to *t* the next locking tooth B has fallen upon the verge and is stopped there as shown by the dotted line *bv*. When the balance returns, the nick slips past the tooth *bv*, and the balance goes on till the pallet has got into the position *p*, with the nick quite

Fig. 59.



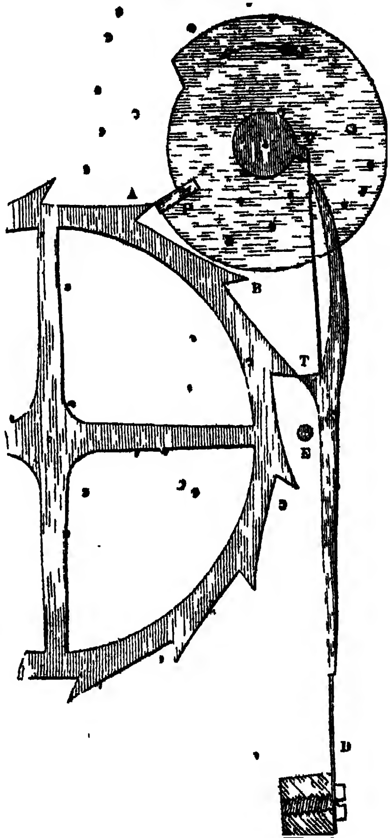
beyond the tooth, and then the balance comes back again in the impulse direction; the tooth enters the nick and the escape begins, the impulse pins moving from *s* to S and from *t* to T without giving any impulse, except the small amount which the balance receives from the long tooth acting on the nick in the verge until it escapes in the position V as before. The balance here is never free therefore, as it is in the lever escapement,

but the cylinder on which the friction takes place is smaller than in the horizontal escapement, and what is of still more consequence, the impulse is given directly across the line of centres, in the most favourable way, which constitutes the great merit of the escapement, and makes it rank next to the chronometer or completely detached escapement, which I shall next describe. But it requires great accuracy of construction, is liable to stop from any sudden twist of the watch which prevents the balance from once swinging far enough for the nick to clear the tooth, and on the whole it seems to be going out of use, as being neither so cheap nor so safe as the lever, and not so good as the chronometer escapement, which is used in all watches requiring very great accuracy.

Chronometer, or detached escapement. The principle of this escapement, as of the lever, seems to have been invented in France, by Julien le Roy; but also like the lever, it acquired its now standard form in England, under the improvements of the first Arnold, who died in 1799, and Earnshaw, the latter of whom appears to have beaten with his ordinary chronometers the picked ones both of Arnold and his other rivals of that time, such as Brockbank, Emery, and others. The second Arnold, who died in 1842, was as different from the real chronometer man, as many sons are from eminent fathers, and owed his reputation first to his name and afterwards to his partnership with the late Mr. Dent, who told me that the business had fallen so low as to be a losing one when he joined it. After Arnold's death, it came into the hands of Mr. C. Frodsham, under whom I have no doubt it has been very successful.

It should also be known that Earnshaw was the first watchmaker who had sense enough to set at defiance the vulgar and ignorant prejudice for 'high finish' of the non-acting surfaces and to leave them 'in the grey,' as it is called. But so long as smooth work which everybody can see is easier than accurate work which few people can judge of, watches like other things will be got up for show. Old Mr. Dent used to say, 'We must work for the fools.' Nevertheless in large clocks we have got rid of this folly to a great extent, and convinced people that painted iron can go better and last longer than polished brass, when the work is properly constructed.

Fig 60.



This drawing (fig. 60) shows the form in which the chronometer escapement has now been made for many

years. The verge has a small tooth V upon it which pushes aside a lever or *detent* V T D as it passes in one direction, but can pass the other way without moving the detent, by merely pushing aside a very slight spring T V set on the end of the detent, which is therefore called the passing spring. The detent is attached to the watch frame by a spring at D, like a stiff pendulum spring, so as to avoid the friction of any pivots, as its motion is very small, and it has a stop T against which the teeth of the scapewheel are stopped as soon as the escape has taken place. It then rests itself against a pin E. The impulse is given exactly as in the duplex escapement, by the scapewheel teeth A acting directly on the pallet P projecting from the verge, although their form is rather different. The impulse begins as soon as the tooth V has unlocked the detent: it is shown exactly in that position in the figure. The detent stop is a little undercut for safety, as the pallets are in the lever escapement, and it is always made of a jewel in good chronometers, and so is the impulse pallet.

It should be observed that both in this and the duplex escapement, the pallet must not really have arrived quite in front of the impulse tooth at the time when the unlocking takes place, because the wheel takes a little time to get into motion, whereas the balance is in quick motion at that time and would therefore have run away from the tooth if it were not given some start, as we may say. If it were drawn in a picture as it really is made, it would look as if it could not act, and therefore I have drawn it not exactly as it is.

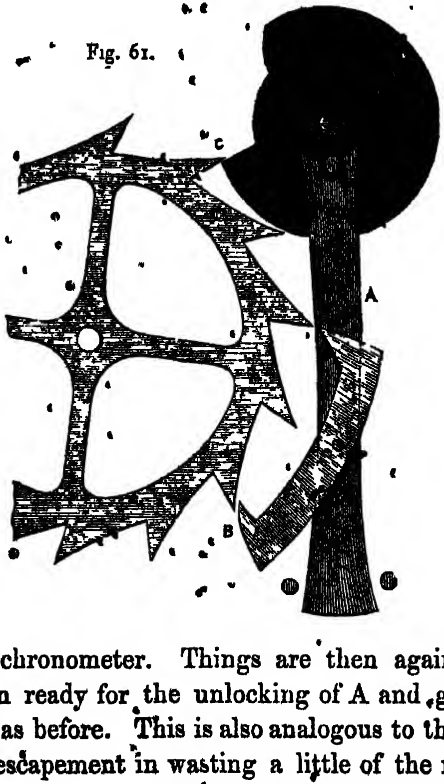
The chronometer escapement has been made on the duplex plan, of long teeth for the locking and short for

the impulse, but I suppose there was not found to be any appreciable advantage in it, as it has never been generally adopted.

Lever chronometer escapement. This is a combination of the lever and the detached escapement, which has been several times re-invented. It is not of much consequence who was the first inventor, and I can only say that I am told by Mr. Arnold of Baker Street, who brought me some of these watches to look at, that there is a notice of the invention, by a man named Savage many years ago, in the Society of Arts' Transactions. Mr. Dent had also had some made, but gave them up because he found they were inferior to the common chronometer. Mr. Arnold says the same, but says also that he has found them less liable to stop from careless wearing, which I can believe, and that they require less delicacy of construction, and can therefore be made cheaper. They certainly avoid one defect of the common chronometer, viz. the unequal action of the weight of the detent, which resists the unlocking in one position, helps it in another, and is indifferent in a third, and also when the watch is lying flat as in box chronometers; which is another reason in favour of them. The action is this. The pallets A B (in fig. 61), which look like the lever escapement, only just lock, and have no impulse. The balance is here represented at the moment of unlocking A and the impulse going to begin at C, exactly as in the common chronometer. By the time the impulse is finished the tooth now between A and B will arrive at pallet B and be stopped there. As the balance returns it will unlock B, which lets the wheel run a very little, just enough to carry

that tooth past the pallet into the position shown in fig. 61, and transfers the locking to A again; and this is what corresponds to the passing of the passing spring

Fig. 61.



in the chronometer. Things are then again in the condition ready for the unlocking of A and giving the impulse as before. This is also analogous to the French virgule escapement in wasting a little of the motion of the wheel in passing from one locking to the other without any impulse.

Remontoires. The escapement for which Mudge received the parliamentary reward I have already spoken of, was on the remontoire principle, and there have been others on the same principle. But they

have never come to any good, and I do not believe they ever will in watches, although I have myself helped to introduce them into large clocks, where it was pronounced equally certain that they must fail. But the conditions are essentially different in so many respects that no inference can be drawn from one which can be of any use for the other. It is sufficient to say that the friction of the train and dial work is the great source of variation in large clocks, and that the pendulum arc varies very little; while the variation of the arc of the balance in a watch is very large indeed in different states of the oil and in different positions, and nothing is more requisite to impress on horological inventors than this, that nothing more complicated than what is now in use has the smallest chance of being adopted. And for that reason I do not think there is any other of the numerous escapements which have been published or exhibited at various times, which it is worth while to increase the size of this book by describing.

REPEATING WATCHES.

I understand that *repeaters* have so completely gone out of use that there are no English workmen now who even profess to make them. In watches as in clocks, all these multifarious indications of time seem to have gone out as greater accuracy has come in; and it is certainly true that time-keepers which profess to perform many feats generally perform them all ill, and frequently require mending to make them go at all. I shall therefore merely indicate the general nature of

the machinery: full descriptions of it may be found in Reid's book and in Rees's Cyclopædia. Watches were never made (so far as I know) to strike spontaneously: but pushing in the handle knob was made to wind up the spring of a striking part to such an extent as the position of the dial-work allowed it to go, as I have already described under the striking work of clocks: and the watch then struck the hour either on a flat bell or on a ring surrounding the works like those spiral springs on which small clocks sometimes strike, and the quarters and perhaps a half-quarter afterwards, on two other rings, or on another less sonorous part of the hour-bell.

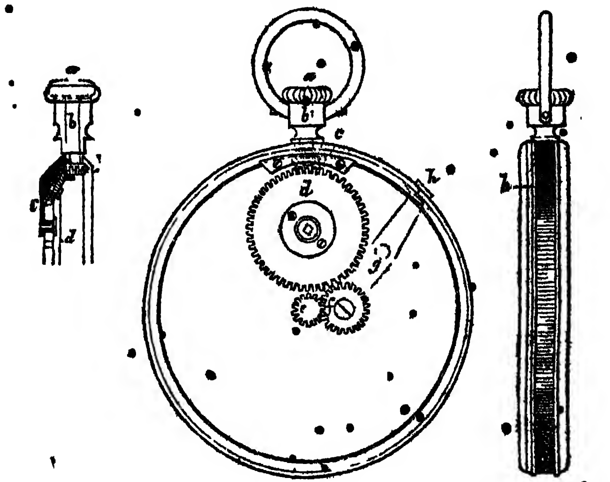
KEYLESS WATCHES, &c

A watch may be made to wind without a key in several ways. One plan is to put a kind of gathering click to the handle knob, which pushes in and takes hold of a ratchet set on the barrel, or the fusee if there is one, and winds it up as you pull the handle out again. But this was very liable to get out of order, and was also objectionable because it pumped air into the watch which produced condensation of moisture; and the following plan (fig. 62) was invented by a foreigner and has been for some years used by Mr. Dent, and lately by some other makers: *a* is a wheel set on a ratchet on the barrel arbor, so that it will only turn the barrel the right way (there is not room to introduce this machinery in fusee watches of the common size); *c* in the left hand figure is an intermediate oblique bevelled wheel between *d* and a pinion *b* on the handle. It is

evident therefore that if you turn the handle *a* the right way you will windup the watch, and if you turn it the wrong way you will do no harm.

But besides this you can set the hands by the handle; for there is a small wheel *e* on the hand arbor

Fig. 62.



with another *f* by the side of it on a lever *fgh*, by which that intermediate wheel can be thrown into gear with *d* as well as *e*, the lever coming through the side of the watch-case; and then it is clear that by turning the handle either way you can turn the hands. If you have to turn the same way as serves to wind the watch you do also wind it a little (and therefore if it is fully wound you cannot set the hands that way); but if the other way, then you do not move the barrel, as the wheel *d* slips on the ratchet.

The advantages of this mode of winding and hand-setting are that the watch has never to be opened, which lets air and dust in, and also that the inner case or 'dome' at the back of the watch is saved, which reduces the bulk and saves enough in cost to pay for the extra machinery.

The winding ratchet is analogous to that contrivance of Breguet's, the most celebrated of French clock-makers, called the tipsy key, which has its handle connected with the pipe by two ratchets which fit closely into each other and are held together by a small spiral spring; and if you turn the handle the wrong way one ratchet only slips over the other. They are chiefly used with foreign watches, which are more easily strained than English ones. The best watch key is one with a long stalk like a pencil, which you can twirl between your finger and thumb, holding the watch quite steady, instead of turning it half round as you are apt to do in winding with a common short key, which disturbs the balance.

Self-winding watch. Napoleon I. had a watch which wound itself up as he walked, by means of a weighted lever with a slight spring under it, which danced up and down at every step, and had a click taking into a ratchet on the barrel.

Pedometer. A similar lever may be made to drive a train like a watch train, but without any escapement, and then it in fact counts the number of your steps and indicates them on a dial. You can adjust it for the number of steps which you usually take in a mile, and then it measures the distance you walk, in a rough and approximate way; but it ought to be understood

that it is really nothing but a step-counter, and unless it is properly adjusted, and you are walking at the rate for which it is set, it is worth nothing for measuring distances accurately.

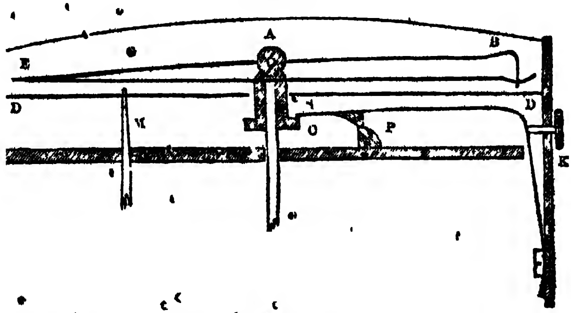
STOP WATCHES.

It is sometimes convenient to have the means of marking a short interval between two observations with a watch, or to mark the exact time of an observation without looking off the thing you are watching. Several contrivances have been invented for this, most or all of them involving some kind of duplication of the seconds hand. In one there are two seconds hands on concentric arbors connected by a very weak spiral spring, and when you push in a pin one of them is stopped, while the other will go on for some seconds without the connecting spring having force enough to stop the watch. But this is clearly objectionable, and a better plan is to have the two hands or their arbors connected by a sort of eccentric disc acting upon a spring which will bring them together again after a separation of not more than one revolution, or half of one. Several watches, of different constructions, on this *split-seconds* plan were exhibited in 1851.

There is also another perfectly different one, which enables you to make a mark on the dial at the exact time when you push in the pin at the time of observation. In fig. 63, D D is the dial of a large watch, with the seconds hand E A B in the middle: the hand is double, and the lower piece of it ends in a little spoon with some thick ink in it and a hole in the

bottom through which a point from the upper hand E A B can pass and make a mark on the dial. That hand is pulled down very suddenly by a lever D P C which slips over a stop P of a shape difficult to describe, being pushed in by the knob K, and is immediately thrown out of contact again with the link A C, by means of which it pulls down the hand. If you want great precision of observation this apparatus should only be applied to a double-beat watch, in which the seconds

Fig. 63.



hand makes 4 or 5 distinct moves in the second, and not a duplex or chronometer, in which there are only half the number of motions of the train.'

I am not aware that there is anything else of a rudimentary character, or belonging to the principles of clock and watchmaking which requires notice. Case-making is not horology, and I have nothing to say about it, except that the cases of what are called hunting watches, which fly open with a spring when you press the handle, cannot be so close against air and dirt, as those which snap tight together. Persons who are afraid of breaking their watch-glasses may be

tolerably safe with 'half hunting watches,' which have only a small and strong glass in the middle of the cap, which may then fit tight, and need never be opened except when the hands want altering. The closeness of the case makes a great difference in the time a watch will go without cleaning. They generally want at least cleaning about every two years; though very good ones, with all the escapement work jewelled and well made, will go 4 or 5 years with no material variation of rate, which I think may be regarded as one of the greatest triumphs of mechanical art. At the same time it should be remembered that letting either watches or clocks go too long without being cleaned and oiled is very bad economy; for as soon as the oil is all gone wearing out of the pivots begins.

Watch dials are either made of gold or silver (which soon tarnishes) or of copper covered with enamel, which is a kind of glass. This belongs to a separate trade. It occurs to me just now that clock dials, both of house and turret clocks, might very well be made of white glass like the Westminster dials, even when not illuminated. Such dials with black hands are more distinct than any other kind, and if the black figures are burnt in with black enamel, the dials would be everlasting and never want painting. Some of the public clocks in Paris have enamelled dials, which are far more expensive than these white glass dials would be.

HISTORY OF THE WESTMINSTER CLOCK.

It would be a natural question to ask how a clock can have a history, except that it was ordered of a clockmaker and made, and that it has gone either well or ill, as the case may be. The first clock at Westminster had a rather remarkable history, to which I have alluded already, having been paid for out of a penalty on a corrupt Chief Justice, at the end of the thirteenth century; and perhaps the motto on the sun-dial on one of the houses now opposite Westminster Hall, '*Discite justitiam moniti*,' may have descended from that event. There was a great bell there too, according to some accounts nearly as large as the present one. It was afterwards translated to the new St. Paul's Cathedral and there cracked very soon, and recast twice within a few years, and with no great success at last. Whether the clock struck upon it I do not know. If it did, it would probably be very feebly, as I cannot ascertain that even now there is any other clock in the world which raises a hammer heavy enough for such a bell.

But although the new Westminster clock has no such history as the old one, it has a very singular history of its own, which I am assured many persons want to see in an authentic form. It naturally divides itself into two distinct periods of about eight years each, in the first of which I had nothing to do with the business, and consequently derive nearly all my knowledge of it from the parliamentary papers; but in the second period I have had a great deal to do with it, and know much more about it than has been hitherto disclosed, or can be by anybody else.

LORD CANNING *Chief Commissioner of Works*.—The

official correspondence about the clock began in April 1844, by Sir Charles (then Mr.) Barry* writing to the Commissioners of Woods and Forests, who then had the management of her Majesty's public buildings, that 'the 'time had arrived when it was necessary to have the speci- 'fications, drawings, and estimates prepared for the clock, '*in order that the walls of the tower might be carried up in 'accordance with the necessary arrangements for the weights 'and machinery;*' and recommending that an offer from Mr. Vulliamy, which he enclosed, should be accepted. That offer was to prepare the plans and specifications and working drawings for a clock with such dials and bells as the architect described, for 100 guineas if he had the making of the clock, but for 200 if he had not. The Commissioners without further inquiry authorised Mr. Barry to engage him to prepare a specification and estimate on those terms. Eight months afterwards Mr. Vulliamy wrote to say that he had only just observed that he was expected to send in an estimate as well as plans, and that that was not included in his offer, and he objected to do it. No official answer appears to this letter; but in the next letter which he received, some months after, it was again incidentally mentioned that an estimate was expected. He still refused to send one, though it afterwards appeared that he had made one 'for his own satisfaction,' and that it amounted to 3605*l.*, including the sum he was to have for the drawings.

Before Mr. Vulliamy had completed his plans the first Mr. Dent applied to the Commissioners to be allowed to tender for the clock. He was told that he should, as soon as the plans and specification were ready. But Mr. Vulliamy's plans were exactly what he meant to have nothing to do with, and he very properly replied 'that he should be 'degrading himself to the level of an executive mechanic' if he consented to make the clock from the plans of another

* It is proper to state that all this history of the clock and bells was in type, subject to corrections of the proofs only, before Sir C. Barry's death.

person in the trade, though he should be quite ready to follow any instructions of the Astronomer Royal or any authority equally eminent, as he had done in making the Royal Exchange clock.

This seems to have opened the eyes of the Commissioners to the mistake they were drifting into; for Lord Canning soon after wrote to the Astronomer Royal and asked him what course should be adopted 'in order that the clock 'might be the very best that the skill and science of the 'country could supply.' Mr. Airy replied that a similar question had been put to him respecting the Exchange clock a few years before. He said that there was no market, or, no such thing as a general competition for clocks of that unusual size and character, and that he had recommended a limited competition (which is sufficient to secure the price being reasonable) of those whom he then believed to be the three best makers in England, viz. Mr. Dent, Mr. Vulliamy, and Mr. Whitehurst of Derby. That it had ended in Mr. Dent being selected without any further intervention of his, and that Mr. Dent had not only carried out all his instructions, but had made some judicious improvements of his own, and the result was a clock which was superior to most astronomical clocks in accuracy, and he had no doubt, was the best public clock in the world. If any maker was to be selected at once, he therefore recommended Mr. Dent, provided he asked a reasonable price.

The consequence of this was that the same three makers were invited to compete for making the Westminster clock, subject to certain conditions laid down by the Astronomer Royal as to the general nature of the construction and the accuracy of the performance; which it is unnecessary to reprint now in consequence of the turn the business took before the clock was made. They were printed in the first edition of this book. But still a singular distinction was kept up between Mr. Vulliamy and the others; for he was communicated with only through the architect, and was

moreover told that he was at liberty to suggest any departure from Mr. Airy's conditions if he saw reason to do so. And that liberty he was not slow to use; for he objected to every one of the conditions of construction which did not agree with his own previous practice in much smaller clocks; and pronounced the conditions of accuracy of performance impossible and absurd, and repeated it after the publication of Mr. Airy's letter saying they had been actually satisfied in the Exchange clock; of which letter there was a formal complaint to the Commissioners that he had got a copy in some mysterious way before it was published. He also objected to the proposed control over the work by the Astronomer Royal on the ground that his letter showed that he was prejudiced in favour of Mr. Dent. In short he refused to compete at all on the proposed terms, but went on with his original plans as if nothing of this kind had happened; and he ultimately sent them to the architect, with various papers of remarks on Mr. Airy's conditions, of objections to him personally, of reflections on Mr. Dent (who for some probably good reason was regarded throughout as his only formidable opponent), and of his own claims to be employed on his own terms. All which was duly transmitted to the Commissioners, and by them to Mr. Airy with the two other tenders.

Mr. Whitehurst and Mr. Dent agreed to all the conditions, and their tenders were respectively 3373*l.* and 1500*l.*, exclusive of some magnetic apparatus which was then proposed to be added. Mr. Airy said he could not account for the astonishing difference between the tenders, except on the ground that Mr. Dent had better means of making such a clock than Mr. Whitehurst, and was probably willing to do so more with a view to distinction than profit. Although he considered it impossible that Mr. Vulliamy could be employed, in the position which he had assumed, he reported on his plans, and summed up his opinion of them by saying that they were the 'plans of 'a large village clock of very superior character and great

strength, but failed altogether in delicacy,' i. e., in all the provisions on which accuracy of going depends, especially in a very large clock. I shall have more to say about this design hereafter, in consequence of the renewed attempt to force it upon the government after my connection with the work began. A well known Clerkenwell firm, who said they had made 3000 turret clocks in 100 years, applied about this time to be admitted as competitors; but they, like Mr. Vulliamy, did not profess to comply with the Astronomer Royal's published conditions, either as to construction or accuracy of performance.

After Mr. Airy's report upon the plans, in May 1847, Mr. Whitehurst disappears out of the business; and there can be little doubt that he would have equally disappeared if Mr. Dent and the Astronomer Royal had been got rid of: for it would have been urged with some force that it was not worth while to reject Mr. Vulliamy for the sake of the insignificant difference between his 3605*l.* and the 3583*l.*, the amount of Mr. Whitehurst's tender + the 210*l.* which would then have had to be paid to Mr. Vulliamy for not employing him; no such arrangement having been made for the benefit of either of the other competitors.

Lord Carlisle *Commissioner of Works.*—What then was done by the Board of Works upon this tolerably decisive report of their own referee? Nothing. Lord Carlisle had handed over to three 'special Commissioners,' the late Lord De Grey and two other gentlemen whose names do not appear, what was called the superintendence of the works at the Houses of Parliament; and they were advised by *somebody* to report to the government in 1849, 'that 'there was no prospect then of any definite period being 'fixed at which the tower would be completed to such an 'extent as to require a decision on the subject of the person 'to be employed to make the clock.' How then was the internal wall question settled, for which the plans of the clock had been required by the architect? If Mr. Vulliamy told me the truth (which I have no reason to doubt), it

was settled by building the walls to suit his plans; and he confidently added (as he afterwards admitted in one of his printed papers)—'Mr. Dent will never make that clock.' How that prediction failed, I have now to relate, leaping over a considerable interval in which nothing was done, into what I called the second period of the history.

LORD SEYMOUR *Commissioner.*—Towards the end of 1851 Lord Seymour, now Duke of Somerset, then First Commissioner of Works, (which had just been severed from the Woods and Forests) wrote to ask me, on the recommendation of the Astronomer Royal, to act with him in the management of the clock business. I had various interviews with Lord Seymour about it, and examined the plans of 1847, or rather such of them as could be found; for some of Mr. Dent's and all of Mr. Whitehurst's had disappeared, and some had been damaged, while Mr. Vulliamy's were quite clean and perfect. The descriptions of them all however had been printed. I was soon convinced that none of those plans would do, Mr. Vulliamy's had been already condemned by the Astronomer Royal, and I should have gone farther than he did in the condemnation, for a reason which will appear presently. Mr. Dent never appears to have been informed of the intended size of the great bell, which governed the construction and size of all the striking work; and consequently his clock was too small for a bell of 14 tons, which weight is distinctly specified in Mr. Vulliamy's papers, and seems also to have been communicated in some unofficial way to Mr. Whitehurst, though not at all to Mr. Dent. I do not understand how that strange discrepancy between the plans escaped the notice of the Astronomer Royal, who seems neither to have observed that Mr. Dent's clock only professed to be calculated for a 7½ ton bell, nor that Mr. Vulliamy's, which professed to be calculated for one of 14 tons, only provided for a hammer very little heavier than those of the St. Paul's and Lincoln bells, which are

not 14 tons, but 5. I suppose Mr. Airy directed his attention chiefly to the provisions for securing accuracy of time-keeping; and he afterwards expressly declined having anything to do with the bells as being out of the range of his experience. Nevertheless he is the person selected by the present Commissioner of Works, Mr. Cowper, to advise upon them, and does not appear to have declined the commission.

Moreover, in that interval from 1847 to 1852, various improvements had been introduced into the construction of large clocks, chiefly through Mr. Dent, which we agreed this clock ought to possess. Above all I was convinced that the business could not be efficiently carried on upon the circumlocution office system which had been followed before; when Mr. Dent had to write to the Commissioners, and the Commissioners to the Astronomer Royal, and the Astronomer Royal to the Commissioners, and the Commissioners back again to Mr. Dent, to settle such points as whether the dial wheels were to be adjustable by tangent screws, or the barrels tapered, and so forth: all which would be much better settled by five minutes' conversation at the factory at the proper time. I knew that it was impossible, and if possible, that it would be absurd and mischievous, to prescribe beforehand a definite design for all the details of such a novel machine as this, with such an unparalleled combination of great size, and therefore great weight and friction of the parts, with extreme delicacy and accuracy of performance, and I was determined not to undertake it on that footing.

The result of this was that Mr. Airy and I proposed to Lord Seymour, and he agreed, to ask Mr. Dent for what increase upon his former tender he would undertake to make such a clock as we then described in a very general way, on the understanding that he was to do everything which we might concur in ordering, and that the whole was to be subject to our approval. Of course such a contract as that could only be made by a person who had full con-

fidence in his referees, and knew that they were not likely to impose anything unfair upon him, and who also felt so much scientific interest in the work as to induce him to run considerable risk of having to do more than anybody could then foresee. Luckily all these conditions concurred, and Mr. Dent offered to do the work on those terms for 1800*l*., or just half the amount of Mr. Vulliamy's estimate. Lord Seymour at once accepted that offer and gave Mr. Dent the order for the clock, a few days before he left the office of works in February 1852; and most fortunate it was that he did so, and put the matter beyond revocation by his successors, as will presently be seen.

Lord John Manners *Commissioner*.—The first thing that occurred after the clock was ordered does not appear in the printed papers, but is not insignificant as an introduction to what does appear. Mr. Dent and Sir C. Barry were both told by Lord Seymour that the architect was to give the clockmaker such information as he might require. This the architect interpreted to mean that the clockmaker was to give him working drawings of the clock; at least he immediately sent for Mr. Dent and demanded them. He replied (according to the account he gave me the same day) that he had no working drawings, and did not expect to have any, but only such sketches from the referees, or one of them, as would be sufficient for his men to work from, with such personal instructions as they would also have; and besides, it was no part of his bargain to be at the expense of making drawings, for which Mr. Vulliamy had received 200 guineas. And so he referred the architect to Mr. Airy and me for any information he required.

Accordingly Sir C. Barry asked us to meet him at Westminster, which we did on the 22nd of March 1852, and showed him the design of the clock so far as it was matured. We then learnt for the first time that the internal walls had been already carried up nearly to the level of the dials on a plan quite inconsistent with that design, although it had been sent to him by Lord Seymour before it was proposed

to Mr. Dent, for the express purpose of ascertaining whether there was any architectural objection to it, and Lord Seymour had had no answer. However it did not follow that the contract must be given up; for I told Sir C. Barry that we should get over that difficulty by the exercise of the power we possessed, of altering the plan as we thought fit. Mr. Dent thereupon asked for and was allowed an additional 100*l*., because the necessity for a different and more expensive plan was caused by no alteration of our opinion, but by the state of the tower, of which we had not been informed at the proper time.

I shall keep the history of the bells distinct from that of the clock, and therefore I only say of the internal walls at present, that the shaft or well provided for the clock is inconveniently narrow in the direction of the length of the clock frame, while it is so much too wide the other way, that part of it has to be built over, and the north and south walls cut off in the clock-room, or nobody could have got to wind up the clock. And the addition of that superfluous space to the adjacent air shaft, or moving the wall between that and the clock shaft eastward by only its own thickness, would have avoided all the difficulty and much of the cost of hoisting the successive great bells up and down the tower. At that time too it was intended to put the staircase in the clock shaft, which is 174 feet deep in the middle of the tower, perfectly dark, and entirely without fresh air, except such as you might take in with you when you opened the door at the bottom. This I did get altered, as the staircase was fortunately not built; but even then it was put in the only dark corner of the tower, and has to be lighted with gas up to the level of the general roofs of the building. To be sure, it has the advantage of a number of windows opening into the chimney called the air shaft, which is itself dark and is filled with the fumes of the ventilating fire of the Houses of Parliament. As the scheme for extending the building westward from the clock tower is happily stopped, and that now brick side of the tower is to be

finished, there may be some chance of the staircase being indulged with windows, and possibly some of them may be made to open into the air of Palace Yard, and not into the foul air chimney of the Palace.

The next move in the game was this. Mr. Airy had declined to have anything to do with the bells, and had gone abroad a few days after our interview with Sir C. Barry, leaving me full power to act for him. I therefore wrote to Lord J. Manners to urge the importance of ordering the bells, or at any rate the great Bell, as soon as possible, knowing that they would take a long time to make, and that we should be very much in the dark as to the construction of the striking part of the clock until we saw what weight of hammer a bell of 14 tons would require. No notice was taken of that letter; but exactly a month after it I was asked to meet Sir C. Barry and Mr. Dent at the office of works; and then this took place. The First Commissioner opened the business by telling Mr. Dent and me that he had been advised that a mistake had been made in sanctioning a contract for making the clock with the large wheels of cast iron instead of brass or gun metal. As our specification had not then been published, it seemed rather strange that anybody who knew or cared anything about brass clock wheels should so soon be in a position to offer advice to the Board of Works about it. Moreover it so happened that this substitution of iron for gun metal wheels had been expressly stated in our specification as a reason why Mr. Dent should not demand any great advance upon his old tender, although the clock was to be made much larger. So if the iron wheels could be upset, there was another very fair chance of getting rid of Mr. Dent's contract. But fair as the chance seemed, it failed again. He and I had very little difficulty in demolishing the brass wheel nonsense; and I well remember Lord J. Manners turning to Sir C. Barry and saying, 'Then I suppose we must be content with 'the cast iron,' and he did not attempt to argue that point further.

But there was yet another gun to fire, which was evidently thought much heavier than the brass one. The Chief Commissioner then informed us that he thought it essential that some more referees should be appointed, including some civil engineers *and the architect.* When the matter reached this point it was difficult to preserve one's gravity. Mr. Dent had contracted to make for the fixed sum of 1900*l.* such a clock as the referees might impose upon him, with no protection against their extravagance or miscarriage, except his confidence in their reasonableness, experience, and skill in designing clock-work; and this it was seriously proposed to alter into a mixed commission, consisting of the architect, who did not profess to know anything of clockmaking, and had recommended another maker, and of a number of other persons who might be eminent in other ways, but would probably have to experimentalise in clockmaking at Mr. Dent's expense before they could be of any use in such a commission. However we did preserve as much gravity as we could, until we got into the street; and we were rather helped to it by the solemnity with which we were assured, when other arguments had failed, that 'it would be more satisfactory 'to the Government and the House of Commons' if we would consent to that revision of the contract. But we were not moved, even by that awful warning; and so we retired, leaving the new Commissioner of Her Majesty's Works and his architect to console one another as they might.

But the opposition tactics were not quite exhausted yet. A few weeks afterwards I received a copy of a parliamentary paper entitled, 'The Memorial of the Master, 'Wardens, and Court of Assistants of the Company of 'Clockmakers of the City of London, to the Right Honor-'able the Commissioners' &c., on the subject of the great clock for the Houses of Parliament. The authorship of it was transparent enough, and indeed Mr. Vulliamy did not deny that it was his, whether with or without some other

aid, I do not pretend to say. As may be supposed, the object of it was to get himself and the sort of committee he wanted, '*specially including Sir C. Barry*' and some of the clockmakers themselves, substituted for Mr. Dent and the Astronomer Royal and me, or anything as near thereto as the Commissioners could manage for them. But these ingenious gentlemen forgot that parliamentary papers are a dangerous game to play at, unless you have a case which cannot be spoilt by answering, or is safe not to be answered. The only effect of the publication of the Clockmakers' memorial was to produce an answer to it in a few days, which disclosed various things which would otherwise have lain quiet, and silenced the anti-Dentine confederacy, and left old Mr. Dent to go on making the clock in peace, for the short remainder of his life. These documents are too long to print here: anybody who is curious about such things may find them all together in Parliamentary paper 500 of the year 1852.

Sir W. Molesworth *Commissioner*.—Mr. Dent died in March, 1853; and there was again a new Commissioner of Works, who might be induced to try his hand at upsetting the contract if some plausible ground could be presented to him. So presently ensued this remarkable concurrence of events. On the 31st of May 1853, the second Mr. Dent wrote to the Board of Works saying that no progress seemed to be making with the tower, and that therefore he could not be responsible for the clock not being completed and fixed by the specified time in 1854. This letter was naturally communicated to the architect; and a few days afterwards, Sir W. Molesworth told me that Sir C. Barry represented himself to be waiting for the clock; and he made various inquiries about Mr. Dent's progress with it and his capacity to finish it.

The statement that the architect was waiting for the clock was so manifestly absurd, from the visible state of the tower, that it is only charitable to suppose that Sir W. Molesworth had misunderstood him. At any rate he was

speedily satisfied that that was impossible. But I afterwards discovered, though not for two years afterwards, when the next batch of Parliamentary clock papers was published, that at the very time when the Chief Commissioner was inquiring of me about Mr. Dent's progress and ability, his secretaries were getting legal opinions whether they could not repudiate the contract altogether. The Crown lawyers at first gave an opinion that they could, and Mr. Dent was written to with that pleasant intimation, accompanied with the benevolent offer to make a new contract on a different footing. But he could consult lawyers as well as the Board of Works, and he sent in a statement of his own, and said plainly that he did not believe any such opinion had been given with full knowledge of the facts. The Attorney and Solicitor General were therefore consulted again; and Mr. Dent's statement being admitted to be correct, they gave a different opinion, which made the Board abandon that creditable attempt at repudiating a contract inherited by a man whose competence to execute it they distinctly admitted, and who had been spending his money upon it for months without a word of intimation that it was intended to repudiate it.

Still there seemed another chance for them. In November 1853 Mr. Airy resigned the joint superintendence of the work, which indeed had been little more than nominal before. The Board evidently suppressed three of his letters relating to this, and probably as many answers of their own, in their next professed publication of '*all* the papers,' &c.; and I shall say no more of it than that it arose from a conversation which he told me he had casually had with Sir C. Barry about the clock, not long after that interview which I have mentioned with Sir W. Molesworth. I may as well add however, that although Mr. Airy's certificate thus ceased to be legally requisite for Mr. Dent being paid, he did go to see the clock two years afterwards, at the request of the then Chief Commissioner, and expressed his approval of it, and his opinion that Mr.

Dent ought to be paid a fair proportion of the contract price. He might have demanded the whole, as the impossibility of completing it was no fault of his, but he only asked for 1600*l.*, and was paid it on Mr. Airy's letter and my certificate that the clock was completed as far as it could be out of the tower.

On his resignation the Board of Works tried hard to make me resign also, pretending that they could not recognise me without him, and actually not hesitating to say that 'they were not aware that his position in the 'matter was altered,' after he had not only formally resigned, but repeated his determination not to act any further! I was equally determined to see the clock made; and as they refused to give me the information required, or to direct the architect to give it to Mr. Dent, I warned them that the clock would go on being made without it, and and that it would probably require some expensive alterations afterwards, especially as we had still no bells; and that the public might then judge who was to blame.

Sir Benjamin Hall, *Commissioner.*—Nothing else of any consequence happened until the first great bell arrived at Westminster and we found by trial what sort of a clock hammer would be required. And then came out the natural consequence of the neglect of the Board of Works to order the bells for $3\frac{1}{2}$ years after I had advised them to do so. All the calculations which had been made about the required weight of the hammers, and therefore the construction of the striking parts, turned out wrong; although we had provided for a hammer of nearly three times the weight of that for which Mr. Vulliamy's clock, approved by the Company of Clockmakers, professed to be designed, though it would never have lifted even that. It was clear from the experiments which were made, of course with the desire to impose on the clock the lightest hammer that would bring out the full tone of the bell, that nothing less than about $\frac{1}{40}$th of the weight of the bell would do, even for the thinner of the two great bells. And this

agrees with what I have found in smaller bells on the same scale of thickness, of which I shall speak afterwards, though we had no means of knowing it when the clock was made.

The clock therefore had to be altered to make it lift heavier hammers, both for the hour and the quarters. Fortunately it was just possible to do this within the confined space allowed us by the mistaken construction of the clock-shaft, without altering the frame, by making the clock to wind up twice a week and putting fewer and larger cams on the great striking wheel, as I have explained under the construction of the clock. It was also necessary to make some alterations in the going part, to adapt it to the illumination of the dials, which had not been contemplated at first, and was not advised by me at all. I am afraid to mention the annual sum which Mr. Fitzroy told me the lighting was to cost; it seems so enormous. I suppose it will be known very soon now. These alterations were made in the year 1857 under a new order from the Board of Works, Mr. Dent consenting to receive only 10 per cent. profit on his expenditure up to the completion of the clock.

LORD JOHN MANNERS' *Chief Commissioner* again.—Postponing the story of the bells for the present, as well as that of the hands, there is nothing further to relate until we come to the fixing of the clock. On the 16th of March 1859 notice was received from Sir C. Barry's engineer, who had been hanging the bells and altering the bell-frame for 5 months, that the clock-room was ready for the clock; and Mr. Dent immediately began to send the heavy parts of it there. But going up a few days afterwards, I found, what I had long expected, that it would be impossible for clockmakers to work there or to observe anything accurately in the clock, on account of the darkness of the room. I therefore told the Board of Works that it was absolutely necessary to have more and larger windows put in, especially as the only light they get comes second-hand

through the semi-opaque glass of the dials, which have no wall behind them, in which the windows are. Of course all the clockmaker's work had to be stopped until the bricklayers and plasterers were again got rid of. And so the fixing of the clock did not really begin till the middle of April 1859, for the simple reason that till then the tower was not ready for it, although the dials and hands had been looking false pretences for nearly two years, and legislators and newspaper editors had been continually 'wanting to know' why the clock did not go, and (as usual) paying no attention to the constant answer that the tower was not ready, because it was not the answer they wanted.

I then told the Chief Commissioner, for the information of the parliamentary interrogators, that the clock would be going by the meeting of the new parliament, on the 31st of May 1859. And so it was: to the evident disappointment of some of the newspaper writers, who had been exulting in their own prophetic incredulity only a few days before, and in fact while the clock was actually going. But now turned up a fresh difficulty. When the design of the dials was altered for illumination in 1856, Sir C. Barry wished to have the prescribed pattern of the hands altered and made more ornamental. I told him they would be made as copper tubes, and that Mr. Dent could put on any reasonable amount of ornament which did not make them too heavy. This however did not suit him, and as things were then going on smoothly, and I cared little about the pattern of the hands, so long as they were light enough and strong enough, it was at last agreed that he should get the hands made himself, subject to my approval as to those points. After a few weeks he asked me to go and look at a pattern hand which he had had made of cast iron. I was pretty sure before I saw it that it would be too heavy; and it weighed nearly 5 cwt., including a small bar put on temporarily to complete the counterpoise; for of course large clock hands must be counterpoised. I therefore

rejected that at once, and said, as I had said before, that the long hands with their counterpoises must not weigh above 2 cwt.; not meaning to be particular to a few pounds, but knowing that proper hands could be made (as they now are) of only that weight, including both the visible and partial counterpoise outside the dial and the remainder of it which it is better to put inside.

The architect's next essay was in gun-metal, and there he certainly succeeded better as far as weight was concerned; for the hand and external counterpoise weighed only 1 cwt. 2 qrs. 14 lbs., and the internal counterpoise (not then made) would perhaps have weighed 3 cwt. more. But then came the question of strength. The hand seemed to me too weak to carry its own weight and to resist any force of wind; but Sir C. Barry and his engineer, Mr. Jabez James, were confident it would be found strong enough; and so it was agreed that that pair of hands should be put up for trial. I heard nothing more of any consequence about them, and saw all the hands on the dials for two years before the clock came, and they appeared to be substantially the same as the pair I had thus conditionally approved. But when the clock was connected with them it was found impossible to make it go for an hour by any adjustment of the counterpoises. After several weeks had been wasted on the attempt I had one of the hands taken off, and then the mystery was cleared up. The gun-metal hands had evidently been found too weak, as I had expected, and had been strengthened, or meant to be strengthened, by screwing thick plates of copper all along the back; then they had been thought too narrow, and had been widened by some more plates of copper, until 81 lbs. of it had been added to each minute hand, or three times the whole weight of the copper tubes of which the present hands are made. This of course involved an enormous addition to the short counterpoises, and so the whole mass of each hand and its counterpoises, internal and external, had been increased to 6½ cwt., or considerably more than the cast-iron

hand which I had originally rejected; and the whole of the hands and counterpoises which the clock was expected to drive was no less than 2½ tons.

We also found that the hands had been fitted to the arbors in a way which no clockmaker ever adopts, without any tapering (see p. 211), so that they shook over through a considerable angle every time they passed the vertical, which threw too much weight upon the clock in one position of the hands and too little in another. By making some new and better fitted counterpoises, we did manage to make two pairs of hands go, but it was hopeless to attempt to drive them all; and so I wrote to Lord John Manners that Sir C. Barry's minute hands must be removed and proper ones made, or the clock could not be completed. I did not then propose to meddle with the hour hands; for although they were equally bad in construction, and one of them has since cracked, they did not prevent the clock from going, because their motion is so much slower and their weight less than those of the long hands. They ought all to be replaced by new ones; but Mr. Cowper refused to have a single new one in the place of the one already cracked, and would have it mended and refixed, not by the clockmakers, but by the engineer; and it stopped the clock again, and that dial had to be disconnected again till the hour hand was altered.

On my announcement that the minute hands must go, one of the old struggles took place, the Board trying to get the making of or the control over the new hands for the architect, and I being determined that they should not, until my responsibility for the work was discharged. It was nothing to them that he had first made a pair of hands too heavy, and then another pair too weak, and then altered them into others which were both too heavy and too weak; but it was something to me, who had undertaken to see that the work was completed; and therefore I told Lord John Manners that I had given Mr. Dent the design for a proper set of hands, and that he or

his successor at the Board of Works might take them off again afterwards if he liked. At last the Board gave in; or perhaps I should say, Lord John Manners went out; and the new hands were made as described at p. 251, and they with their counterpoises weigh exactly what I said they should three years before, and less than one third of the removed ones, which were sold for 39*l.* as old metal, after costing nobody knows how much. A pretty good indication this is, of what would have been the success and cost of the clock, if Lord Canning in 1845 and Lord Seymour in 1852 had not stopped it from drifting into the course in which it was intended to go.

The cost of the clock, including all the alterations rendered necessary by the absence of the bells till after the clock was made, and by this affair of the hands, was under 3400*l.*; which is less than the mere *estimate* for the rival plan of Mr. Vulliamy and the Company of clockmakers, which he refused to send in as a tender for a contract. If that rival plan had been adopted the whole clock must have shared the fate of Sir C. Barry's hands; for the rate of going of such a clock with dials of that size would have been a national disgrace; and the absurd inadequacy of the striking work may be judged of from these two simple facts: the great hammer was to be lifted by pins on the second wheel, only ⅛ inch thick, which correspond to steel-faced cams cast on the great wheel of Mr. Dent's clock 2½ inches thick; and Mr. Vulliamy only professed to provide for a hammer very little heavier than that of the before-mentioned Hôtel de Ville clock at Paris, which he himself put forward as his model of large clockmaking; and yet the bell of that clock weighs only one-fourth of the 14 tons which his specification assumed the Westminster bell to be.

Of course Mr. Cowper and the Board of Works knew the real cost of the clock as well as I do, when they so stated it as to lead the House of Commons and the public to believe that it has cost more than 22,000*l.* The only

other sums which I have had to certify besides the 3400*l.*, are 5966*l.* for the bells, which again is within the estimate given to Parliament before they were ordered, though it includes the 570*l.* paid to Mr. Mears (besides the value of two tons of metal) for his very successful recasting of the great bell; and some small items amounting, I think, to 320*l.* altogether, for engineering work not belonging either to the clockmaker or the bell-founder. With all the rest of the 23,000*l.* (or whatever it may be) for dials, hands, bell-frame, and 'other incidental expenses,' I have nothing at all to do. All that belongs to the architect.

MR. FITZROY *Commissioner.*—The clock began to strike the hours in July 1859, and the quarters in September: another delay and more expense being incurred by the floor of the dark room above the clock being found too weak to carry the cranks and levers by which the quarter-hammers are connected with the clock. And on the 1st of October all the striking was stopped by the Board of Works, on their being informed by me that the great bell was cracked. Why the quarters should have been stopped, I do not know, and I told them it was unnecessary; but I had quite trouble enough to get leave to examine the great bell without taking any more to convince the Secretaries of the Board of Works that the quarter bells were not likely to catch the same disease by being allowed to perform in the presence of the cracked hour bell.

In the last interview I had with Mr. Fitzroy we had arranged all that seemed necessary for Mr. Dent's delivering up the clock complete in a few months, and then having it opened to the inspection of the public, of course under the control of the clockmaker who is responsible for it, as it is found elsewhere that in no other way can mischief be prevented; and considering the unusual jealousy which this affair has excited, it is quite certain that no opportunity would be missed of doing anything that would depreciate the character of the clock. It is due to the memory of Mr. Fitzroy, as well as to Lord

Llanover and the Duke of Somerset, to say that I never had the least difficulty in getting any suggestion attended to by them personally, and always settled amicably, whichever way it was settled; and that I was always treated by them as if they did not forget that I had been for years taking more trouble in this matter than anybody else can know, with no possible advantage to myself, except the satisfaction of seeing the greatest horological work in the world executed in the best way, and with no waste of money.

MR. COWPER *Commissioner*.—The present, ninth Commissioner of Works since the business began, has a different view of things. He has not followed one single suggestion which he has received from me, unless it has been confirmed by other advisers, whom he consults behind the back of the person who is considered by the public responsible for the success of the clock. He tells the House of Commons that, among other persons, he has consulted the Astronomer Royal 'who is a very good judge 'of clocks,' and that after the clock is *completed* under my superintendence it is to be handed over to Mr. Airy to be *altered* in the striking parts: an arrangement which appears remarkably rational on the face of it.

I am far from meaning to reflect on the Astronomer Royal for giving the best advice he can on any scientific question asked him by the Government. He has himself written to assure me that in his opinion 'the clock is far 'better in my hands than in any other person's, and that 'indeed he does not know any other person who could 'superintend it;' as it certainly must be superintended by somebody, now that Mr. Dent is dead; though he might have been very safely trusted with it without any control, not merely from his great skill and experience, but from his having such an interest in its successful performance as nobody else can have—except, I suppose, myself.* But I

* Mr. Cowper certainly has an eminent example before him in his management of public clocks. Just when the late Mr. Dent was dying,

am sure Mr. Airy would have told Mr. Cowper if he had asked him, that he has no experience and no special knowledge of the striking work of large clocks, and still less of bells; about which also Mr. Cowper imposes on him the trouble of advising, though he might have learnt from the papers in his own office that Mr. Airy expressly declined that part of the business in 1852. The truth is—for Mr. Cowper has at last let it out—that he, or his master, wants the striking to be reduced; and he has adopted or invented the sagacious idea that a large cracked bell can be made into an imitation of a smaller sound one by some new mode of striking. He certainly shows more sagacity in not asking me to undertake any such operation upon the clock. Whether he will persuade the Astronomer Royal or any other scientific person to risk his credit upon it, I do not know. But I do know that any such folly can only end in wasting money, and that the clock will have to be altered back again, and of course a new bell made, as nearly everybody in London seems to know by this time, except Mr. Cowper and his colleagues.

To be sure, he is only carrying on that 'zigzag principle' on which another great institution was said to work, and which has prevailed with almost unbroken uniformity from the beginning of this business; for every Commissioner who has done anything towards forwarding it, or managing it in a rational way, has been succeeded by one, and once by two, who have done their best to obstruct or mismanage it. Thus too we have seen the new

the Gresham Committee, which is practically the London Corporation, under a clockmaking Lord Mayor, bethought themselves that the time was arrived for making a new arrangement for the care and winding of the Exchange clock; and the result was, that they took it out of the hands of Mr. Dent, who had spent far more upon it than he had ever got for it, and had actually charged them nothing since it was repaired and the latest improvements introduced in 1854, and I know did not intend to do so if they had been quiet; and then, by way of securing its being attended to in the best possible way, they put it into the hands of a well-known firm who never made such a clock in their lives, and have been more active than anybody else in publishing abuse of Mr. Dent's clocks.

Westminster bridge begun, and then stopped for several years, and one Commissioner destroying the flowers, the seats, and the walks planted or made by his predecessor, and 14,000*l.* spent on a scheme for cleaning out a pond which has to be abandoned before it is finished, and a quarter of a million in ventilating and warming, and ten times that sum, and three times the architect's estimate in building, the Palace of the Legislature; and now we have Mr. Cowper of course put where he is to turn out the first architect of this age, who had been selected by a previous Commissioner for the new public offices, and to put in Sir C. Barry's son, or some other gentleman in the Italian line, if the House of Commons will allow it.

So ends the history of the clock up to the present time, having already seen the deaths of the three clockmakers, the architect, and two Commissioners of Works, whose names are involved in it. What further vicissitudes it may have to go through, I cannot pretend to guess, save as the future may be divined from the past. Too many people have had to be disappointed, defeated and exposed in getting it there, for its existence to be easily forgiven, or for any of its occasional failures, such as all machines are liable to, not to be magnified into radical defects if possible. Among them are persons who evidently understand how to 'make things pleasant' both with Government Boards and with that sub-editor of the *Times*, who, in the spirit of an Irishman paying off a grudge with a rifle behind a hedge, tried to ruin Mr. Dent last year by pronouncing him 'evidently an adept only in the art of how not to do it,' because Mr. Dent had told him, that if he had either inquired, or looked into the clock-room, he might have learnt that the clock was waiting for the tower, and not the tower for the clock, as his newspaper had several times told the world.* So when

* This is the gentleman who acquired an enviable fame by pretending to guess at and publishing the name of a correspondent of the *Times*, with whom he was carrying on a little theological controversy in letters to his own newspaper under a well-known *alias*. This, it seems, is the use of

the clock stopped striking one Sunday, while it was notoriously unfinished, that was thought important enough to be announced in the largest type and most conspicuous place in the *Times*, and the attention of the Board of Works invoked. And then comes Mr. Loseby, with more than even poor old Mr. Vulliamy's hatred of Mr. Dent, and of everybody who has supported him (for reasons apparent enough in this book), and he and the clerk of the works at Westminster constitute themselves into a Greenwich Time Commission, set up a clock in the said clerk's office, and publish what they call variations of the rate of the great clock, measured by the striking of the quarters, which variations had been corrected before they were published, as described at page 257.

Meanwhile, anyone who has really accurate means of judging can observe that this huge cast-iron machine, which has to drive through all weathers such a weight of hands as no other clock has in the world, keeps better time than the best public clock you can find of the common construction and common size. And it should never be forgotten that the designer and supporters of the rival plan confessed that they could do no such thing, and derided the possibility of making a clock of this size keep accurate time at all. According to them, it would have been simply one more clock in Westminster, a sort of conventional appendage to a great public building, but worth rather less than usual as a standard of time.

THE WESTMINSTER BELLS.

I HAVE already mentioned that soon after the clock was ordered in 1852 I advised the Board of Works to take some steps about the bells. No notice was taken of that letter,

that arbitrary rule introduced by the managers of that exemplary publication, that 'correspondents must send their names *in confidence*, though not necessarily for publication:' a rule for which there is no justification, except where facts are stated which ought to be vouched for.

nor was anything done in the business for nearly three years — in fact until the clock was all but finished. But about six months after the failure of the attempt to repudiate that contract, on the ground of the first Mr. Dent's death, Sir W. Molesworth sent for the second Mr. Dent and asked him some questions about the bells, on which he was to communicate with me. I desired him to refer the Board to my letter of April 1852, only adding that Messrs. Warner of Jewin Crescent ought then to be included in any competition, with Mr. Mears, and Messrs. Taylor of Loughborough, who were the only English makers of large bells at the time of my former letter. Then there was some correspondence between the Board and Sir C. Barry, from which there is nothing material to extract. His advice was in substance the same as mine, except that he recommended that the commission should be given to Mr. Mears, unless there was to be a competition, I suppose because he had succeeded so well at York and the Exchange. However it was settled that there was to be a competition, and so there was no occasion to discuss that question. He also recommended that I should be asked to prepare a specification, and that the work should be superintended and certified by me, and the Rev. William Taylor, whom I had previously mentioned as the only person I knew who had paid any attention to this subject.

As no less than three persons of that name have now been connected with the making and certifying of bells, and two of them at least are constantly confounded by the newspapers, it may as well be mentioned that the Rev. W. Taylor, one of the referees of the Westminster bells, is not Mr. Edward Taylor, the Gresham professor of music, who was the referee of the second peal cast by Mr. Mears for the Royal Exchange after it was rebuilt, and refused to certify his approval of them. And as the identity of name in the referees is not the only common point in the history of the Westminster and the Exchange bells, I will say a word

more about them here. After Professor Taylor's refusal to certify them as they were, or to examine them any more, Sir H. Bishop was applied to, and he evaded giving any opinion beyond expressing a significant hope that they might be made right, adding that the public must form their own judgment of them. Mr. Mears afterwards got some musical certificates that they were in tune (which a set of iron pots may be as well as the best bells in the world) and at last he was paid for them. The public however did form their own opinion, and that opinion was such that Mr. Mears deemed it expedient to publish a paper (from which these facts appear) for the purpose of showing, exactly as in his Wesminster affair ten years afterwards, that the clockmaker and the chime machinery were in fault, and not the bells at all; which, he added, must be good ones because they were cast from the patterns of the Bow bells; whereas nothing could prove more decisively that they were badly cast, since the sound of the two peals was very different, while the shape and size were the same.

Notwithstanding this demonstration of the excellence of the bells, and various alterations in the chime-work to meet the suggestions that were made, the Gresham committee at last stopped them altogether; and soon afterwards sent the whole 15 bells to Messrs. Taylor of Loughborough to be re-cast, *for the third time.* Mr. Mears's first peal I never heard, but the short time it was allowed to stay there is tolerably conclusive as to its merits. Of the second I should have condemned every bell but one, which was so good that it was difficult to understand how it got into such company. At the Exchange too, as afterwards at Westminster, Mr. Dent's men found that there were holes in the sound-bow of the largest bell (which weighed $2\frac{1}{2}$ tons), after the clock hammer had been striking on it for some time, which fully accounted for the badness of the tone. Not that we must consider this anything remarkable, after Mr. Mears's public declaration by his counsel lately, that he considers it impossible to cast large

bells without holes, and that it is the regular practice at his foundry to stop them up with resin and bell-filings before the bells are shown to the referees, when there are any referees.

Messrs. Taylor's new peal at the Exchange had not been completed to the satisfaction of the referees there, at the time of making the Westminster contract, and it was spoken of as unsatisfactory by Professor Wheatstone, who was consulted by the Board of Works, as I shall mention presently. I had myself suggested to the founders to offer to re-cast the bells so much smaller as to make the job pay for itself, as might easily be done to the great bells of York and Oxford, and with no loss, but a great gain both of power and quality of tone, because they are so bad; but I strongly advised them not to attempt to reproduce the same notes with bells of only ⅘ths of the weight, according to the modern practice which all the founders follow, unless the contrary is ordered. That part of the advice they did not follow, and the consequence is that their Exchange bells, though better than the previous ones, are by no means what they ought to be. I shall have more to say about this modern system of making thin bells hereafter; it is enough to say at present that the tenor bell of this new Exchange peal is of the same note as those of Bow Church, and the old York Minster peal (copied also in the new), and the once famous bell of Sherborne, but the weight is only 33 cwt. instead of 53. It is plain that either the old or the modern scale is wrong, and you have only to listen to learn which it is.

I was asked by the Board of Works to prepare a specification for the Westminster bells in February 1855: which I did, notwithstanding their behaviour about the clock a few months before. They were pleased to approve of it, with some alterations of no consequence; but they proposed another alteration of very great consequence, viz: the addition of the First Commissioner himself as a referee. As he could not possibly be of any use in superintending the construction of a peal of bells, it was clear that when-

ever he acted at all, it could only be for the purpose of obstructing the other referees at the suggestions of somebody else behind the scenes, exactly as two successive commissioners had been then trying to do for several years in the clock business. Mr. Taylor and I at once refused to act upon that footing, and so the business was again put off. At last Professor Wheatstone was consulted. He did not profess to know anything of bell-making; but he spoke even more strongly than I had done of the failure at the Royal Exchange. Indeed he went so far as to say that 'the 'unsatisfactory result there showed that no known bell-'founder in England could be relied on,' and proposed to try a foreign one; though he gave no reason for assuming that the foreign bell-founders were any better than the English. He proposed, and the proposal was adopted, that a commission should be given to Sir. C. Barry and himself to look about them at the Paris Exhibition, where they were going, 'and to collect information respecting the most 'esteemed chimes in France and Belgium, and whether 'there are not in either of those countries makers ac-'quainted with the traditions of the art, or who have 'applied the modern discoveries of science to the improve-'ment of bells, or to efficient substitutes for them:' a tolerably wide commission certainly, and not very distinctly aimed at the only practical question, whether there was any bell-founder who could be safely trusted to make a peal of bells of which the largest was to be 14 tons, as prescribed in 1846.

They made no report of the information they collected; but Mr. Wheatstone communicated it, or all that he thought valuable, to Mr. Taylor and me when we were all three appointed referees afterwards, though he never otherwise acted in the business. The foreign bell-founders appear to have kept their secrets very well (if they have any) except as to what they professed to be able to do, and the prices they should charge; and it was clear that in that respect at any rate there would be little or no

advantage in going abroad and so abandoning all control over the work. There was no evidence of any existing foreign founder having cast a bell of even 5 tons; and there are now at any rate two new bells in England of 4 tons, which are both (if one may venture after late experience to say that of any bell before its inside is looked into) perfectly sound and good castings, and also better in point of sound than any other great bell in the kingdom. These are the 4th quarter bell at Westminster, and the rather larger one cast by the same founders for the Leeds Town Hall from the pattern of the Doncaster bells, which I shall describe hereafter.

In August 1855, Sir W. Molesworth left the Board of works to rule over the colonies; and Sir B. Hall (Lord Llanover), who succeeded him, immediately wrote to me expressing his regret at the differences which he found had prevailed between the Board and me, and asking if I would still undertake the business, with Mr. Taylor and Professor Wheatstone, substantially on the same terms as I had proposed six months before; and I at once consented to do so. Accordingly my specification was sent to all the English bell-founders who were supposed to have the means of executing such a large work, Messrs. Mears, Taylor, and Warner, and tenders were received from all of them. Mr. Mears was pleased to say lately by his counsel, that he lost the job, although his tender was the lowest, because I was determined that Messrs. Warner should have it; and therefore I shall now publish the real reason, which I have hitherto withheld.

It is true that his tender was the lowest; but it was accompanied with an objection to submit to the referees, who, he told the Board, were prejudiced against him; exactly as Mr. Vulliamy had objected to the Astronomer Royal as the referee of the clock 'because he had shown himself to be prejudiced in favour of Mr. Dent' by saying he had no doubt that his Exchange clock was the best public clock in the world. It must be confessed that if

'prejudice' means judgment founded on experience (which is only just the opposite of its real meaning), all the three referees were prejudiced against Mr. Mears. My opinion of all his most recent large bells was well known, and had been published in the papers already referred to, and so had Mr. Wheatstone's, as just now stated; and Mr. Taylor's opinion of the great bell of York (where he lived when it was hung) was, it seems, equally well known to those who were interested in knowing it. But that singular coincidence of 'prejudice' among the three persons who happened to be consulted would perhaps strike the Commissioner of Works as proving something rather different from their unfitness to be referees. At any rate they were not removed to please Mr. Mears, any more than Mr. Airy was to please Mr. Vulliamy; and although he said also that nobody else had the means of executing such a piece of bell-founding, Lord Llanover preferred to try the other founders who made no such objection; and Mr. Mears found out, when it was too late, that he had been a little too confident of getting the job on his own terms: a lesson by which he took care to profit when he had another opportunity of tendering two years afterwards.

Messrs. Taylor's tender was also lower than Messrs. Warner's. But they required two years for making the bells, and an advance of money for the metal, which the government was not disposed to make if it could be avoided. Probably that might have been got over on proper security being given; but they also showed by their tender that they intended to make the great bell thin, as they had done at the Exchange, and elsewhere. I had then no idea of giving the design myself, but I knew that that thin scale of bell-making was contrary to the practice of all former ages and of all countries, and that the effect was bad; and therefore I was not disposed to urge Lord Llanover to stretch the point of the money advance in their favour; and so they also lost the honour of being the bell-founders to Her Majesty at Westminster, and it necessarily fell to Messrs.

Warner. So now Mr. Mears, and everybody else whose expectations or projects have been defeated in that business, know exactly how much of the disappointment they owe to me, and how much the founders themselves played into my hands, if I wanted Messrs. Warner to be employed, and Mr. Mears in particular to be rejected.

The way in which it came to pass that I had to design the bells, was this:—When we came to talk about the contract, Messrs. Warner refused to be responsible for the notes of the bells. Up to that time their method of casting bells of any required notes had been to copy the pattern of some existing ones of the same note. How far that plan would have availed them for a peal of this unusual size may be judged from this: they were convinced, by what mode of calculation I do not know, that the fourth quarter bell would have to be 6 tons, to produce the proper note to suit the great bell, and quietly derided me for saying it would be under 4 tons: it is 78 cwt. They then used also the same soft composition (4 copper to 1 tin) for church bells, which answers well enough for hand or house-bells, but which they have abandoned in large ones for a harder and better sounding composition, since they learnt better from the Westminster experiments. At last I consented to take the responsibility of all *except the casting*, provided I was allowed to make some preliminary experiments to determine the best form and composition. The experiments only cost about 120*l.* out of the 5966*l.* which the bells themselves have cost, including the re-casting of the great bell by Mr. Mears.

I shall explain the practical results of the experiments in the chapter on the construction of bells; but there is one peculiarity in the shape of these bells which I must shortly explain here, because on it depended nothing less than the possibility of getting the great bell into its place without pulling some part of the tower to pieces.

The weight of the great bell had been fixed at 14 tons, apparently by the architect himself, long before I had any-

thing to do with it, I suppose in order to make it exceed the largest bells that had been cast in England, viz: those for Montreal and York Minster. But the strange thing is that, although the tower is 28 feet square inside, and was specially built for the clock and bells, it is cut up into wells, or shafts, of which the only one open from top to bottom is 7 inches narrower than the Montreal bell of 13 tons, and 4 inches smaller than the York bell of 11 tons; and there is no space whatever left in the tower wider than 8½ feet, or about 9 inches less than the diameter of a bell of 14 tons. Over or in that wider shaft too, was to come the clock (which weighs nearly 5 tons), and three floors, of wood, iron, and stone, and an iron chamber for the pendulum, and a large mass of iron called the pendulum-cock, and two iron beams, all built into the walls. Of course not one of these things could be fixed till the bells had gone up if indeed by any contrivance a bell 9 feet wide or more, could be made to go up that 8½ feet opening; and of course they would all have to be taken out again, if ever the bell had to go down again that way, and would have to be afterwards replaced at an enormous expense.

Fortunately it occurred to me to make an alteration in the shape and construction of the bells, which reduces the total height to ⅚ of the diameter. This made the first bell low enough to be taken up the clock-shaft sideways in a cradle; which, although it was more difficult than taking it up in the straightforward way, mouth downwards, was infinitely better than taking it up outside and then landing it in through a great hole cut in the top of the tower. It appears from the newspapers evidently speaking from authority that the people who have been at work hoisting and hanging the bells and making and altering the bell-frame for two years now, have actually not discovered that the second bell is so much smaller than the first that it can go down, and of course a similar new one can go up, the air-shaft sideways. For it is inconceivable, that if they knew the bell is only 7½ feet high, and their

own air-shaft 8 feet wide, they could deliberately propose (as they do) to pull everything to pieces for the mere pleasure of sending the bell down or up the wrong shaft, which, though 6 inches wider than the other, is still 6 inches narrower than the width of the bell. But nothing is surprising there. The taking down of the cracked bell and the taking up of the new one ought to be made a matter of contract with an engineer, without any architectural interference, the contractor taking all the risk.

The reduction in the height of these bells is chiefly due to the substitution of a crown or head like a low mushroom, or a button with a thick neck, instead of the 6 ears or *canons* usually cast on the top of bells to hang them by, and which are necessarily taller. An iron collar in two halves embraces the neck of the mushroom, and is fastened to the beam above by 6 bolts. The clapper-bolt (if there is one) goes through a round hole in the mushroom, and square through the beam or stock; so that when all the bolts are loosened a little, the bell can be turned into a new position after it has got worn in one by the clapper or the clock-hammer.

Even this small matter met with the usual stormy fate of the horological improvements at Westminster. A Mr. W. L. Baker had tried to persuade me to get the bells made and hung according to a patented plan of his, by a single bolt through the crown, which was to be also the clapper bolt. I found that nobody would use it except for very small bells, for which it had been used occasionally, long before either Mr. Baker's patent or nativity. I was no more disposed to adopt it than the bell-founders; and as everybody seemed to approve of the mushroom top for these bells, it was used, as it has since been for some others. Mr. Baker, having first pronounced it worse, next set to work to prove that it was identical with his own, in pamphlets and periodicals innumerable; which I left unanswered, as he generally gave a picture of the two plans, which was the best answer to him. Like one of the giants

in a celebrated history, 'he has a brother far more savage than himself,' a clerk in holy orders in Northamptonshire; and he delivered and published a lecture on my iniquity to an Archæological Society in those parts, and sent me a copy of it, with a threatening letter of I don't know what consequences, if I did not compensate his brother for having the Queen's bells made with what he was pleased to call an infringement of his patent. I believe Mr. Baker afterwards made one of that annual number of about 2000 inventors who have got wise enough to let their patents die at the end of the three years which the first payment covers. And after all this, I found in a German book a description of the mushroom top itself having been used probably as long before my time as Mr. Baker's central bolt was before his, as I am always prepared to find in the case of any mechanical invention for any tolerably obvious object. The only objection to it for common use is that it makes the iron-work more expensive. I shall describe hereafter another improvement in hanging which does not.

The first great bell was cast by Messrs. Warner at an iron-foundry belonging to one of their family at Norton, near Stockton-upon-Tees, on the 6th of August 1856. I went there and saw it as soon as it was taken out of the mould, which came off leaving the bell quite clean, and without either holes, or seams or 'fins' sticking out of it into cracks in the mould; and so neither this, nor any of Messrs. Warner's bells that I have had to look at, required a fortnight to dress and '*trim*,' and prepare for the referees, like a certain other bell which I shall have to speak of presently. It deviated however half a note from the intended E flat, and exceeded the intended weight by nearly 2 tons, in consequence of an excess in thickness beyond the pattern, which the founders could not account for; and the further consequence was that the metal so nearly ran short, that the mushroom crown was not perfect, and the top of the bell was visibly porous, from the want of a sufficient head or pressure of metal above it. Except

that we have gained some useful experience by the subsequent discovery of the internal defects both of this bell and its successor, I should say it was unlucky that the metal had not run a little shorter, and ensured the rejection of that bell at once, and saved us from the still worse failure of the second. Its diameter was 9 ft. $5\frac{1}{2}$ in.; the height 7 ft. $10\frac{1}{2}$ in.; thickness of sound-bow $9\frac{5}{8}$ in. The weight was 15 tons 18 cwt. according to the weighing in the north, but it fell to 15 tons 13 cwt. when Mr. Mears weighed it two years after for old metal: which was right, I do not pretend to say, as it was no business of mine to certify the weights; and I heard that there was a still greater difference between the weighing machines in London and the north in the case of Mr. Mears's great York bell, but in the opposite direction. In that bell too there is a still worse miscarriage in the thickness, for it is $8\frac{5}{8}$ in. thick on one side and only $7\frac{7}{8}$ on the other; the Westminster bell was of equal thickness all round, though not of the thickness prescribed. No wonder that the York bell is so bad as it is, especially as it has holes in the surface also, and scabs or blisters under the surface, which the striking of the hammer has revealed.

The bell was tried at the foundry with an experimental clapper of 7 cwt., which however was quite inadequate to bring out the full sound; and therefore the permanent clapper was made 13 cwt., which might have been reduced to anything less if it was found too heavy. It was tried at Westminster with this clapper in November 1856, and so far from its being found too heavy, it required to be pulled by at least six men to bring out the full sound, and ten were not too many. No one who remembers the newspaper accounts of it need be told that the admiration generally expressed was so great that it would have been useless and absurd for the referees to refuse their certificate, either on the ground that it required a clapper beyond all expectation, or that the casting was bad at the top, or that it considerably exceeded the prescribed thickness and

weight. For it would have been answered, and not unfairly, that the bell proved itself to be right in the opinion of nearly all who heard it, and there was no proof that either the thickness I had prescribed, or the weight of clapper I had reckoned on, would have been any better. Nevertheless Mr. Taylor, though he had not the same paternal reason as I had for preferring the pattern which had been given, did certify his approval very unwillingly; and the cracking of the bell within a year certainly proved that no injustice would have been done if we had absolutely refused to certify and the Board of Works to pay for it.

Of course the founders declare that the cracking was no fault of theirs: that was quite impossible: 'if the bell had 'only been struck with a clapper of 5 or 6 cwt. it would not 'have cracked.' Most likely not; and if every bell that was ever cracked in the world had been struck with a clapper of only half the weight that cracked it, it would probably not have been cracked. But with all submission to the bell-founders, I am of opinion that a bell which will not stand such a clapper or hammer as is actually found necessary to make it sound properly, is *ipso facto* proved to be a bad one, although it may be difficult or impossible to ascertain until it is broken up and the metal examined, what the real or the principal defect is. In that bell of Messrs. Warner's there was no difficulty in discovering one quite sufficient defect, viz.: the excess of thickness, not merely of $\frac{3}{8}$ in. in the sound-bow (which would have done no harm), but an increase from $4\frac{1}{2}$ in., which was the prescribed thickness above the sound-bow, to $5\frac{5}{8}$ in. That was the cause of the excessive obstinacy of the bell in speaking out except under a clapper of that unusual weight; and Messrs. Warner are perfectly right in saying that that cracked it. The only difference between us is, that I think the fault lay with those who made the bell so different from the prescribed pattern, and contrary to all precedent besides, as to require a force to bring the sound out which the bell itself would not stand; while they

want to throw the blame on those who ordered and rang the clapper so to make the bell give out its sound.

But it never is the founder who cracks a bell. Even if he makes the clapper and hangs the bell he does not ring it; and bells do not crack of themselves. The above mentioned bell of Sherborne Church, called Cardinal Wolsey's, though it had been recast in 1670, cracked almost immediately after it was rehung and the clapper altered by Mr. Mears in 1858. Of course the ringers did it. His first Montreal bell of 7 tons cracked about as soon as the two Westminster bells; and he and the people who saw the fracture there have very different opinions about the cause. I know a gentleman who saw it broken up. And we know that he and his allies were going to swear that his Westminster bell was cracked by the hammer being too heavy, although it was within the weight specified in his contract, and lighter in proportion than the ringing clappers (which always strike much harder) of the great bell of Paris and other foreign bells.

But as Messrs. Warner are pleased to insinuate that I cracked their bell, as well as Mr. Mears's, and we have learned something of its constitution since it was broken up which could not be known before, I shall say a little more about it. Besides that fatal mistake in the thickness, the porosity which was always visible at the top, from the metal running short, was found to go much deeper than was suspected; and the metal throughout was very inferior in density to the bits that were cut from the runners at the top and the *fins* at the bottom of the bell; though the porosity was very much less than in the second bell. But worse than all this, Mr. Mears found in breaking it up, that there was a place about 18 in. by 5 in. inside the sound-bow, where the two streams of metal had never united: at least that was the opinion of the learned in such things. One of the sides of this natural crack came into Mr. Taylor's possession, and was borrowed of him to exhibit at the Civil Engineers' Institution after Mr. Mears's bell had cracked.

It is true that this was a mere accident, and a very singular one, and not likely to occur again as Messrs. Warner now cast their bells: but there it was; and so I think this 'great success' of theirs (which still figures in their advertisements) and Mr. Mears's 'magnificent casting' may pair off without much injustice to either of them; though it must be added that Messrs. Warner have since been really successful in two bells of unusual size; while Mr. Mears declares it to be impossible to cast large bells less porous or more homogeneous than his.

Mr. Mears's bell. When the first bell cracked, neither the Commissioner of Works nor the referees had any desire to take the re-casting out of Messrs. Warner's hands. But just as Mr. Mears had lost it in 1855 by making sure of getting it on his own terms, so did Messrs. Warner in 1857, by making sure that Mr. Mears would not be employed on any terms, and standing out for a price, of which I will say no more than this: Mr. Mears's price for re-casting was just 50 per cent. above the price which is almost invariable for bells of all sizes (for in casting large bells there is less moulding to do than for small ones in proportion to the weight of metal); and yet Messrs. Warner demanded a price which would have come to a little more than twice what Mr. Mears received. The consequence was that he got the job, and they lost it, and apparently consider themselves as ill-used as he did in having lost it the first time; and they expect it to be forgotten that when they got it they had some of the fundamental principles of their art to learn, and received an unheard-of price besides, for casting 24 tons of bell-metal, two thirds of which was a complete failure, and ought never to have been paid for.

Ever since Mr. Mears's bell cracked, he has had the advantage of telling his own story almost without contradiction. The gentleman who does the science of the *Times* —and many other things as well—and evidently derives a good deal of information from some particular friends of mine at Westminster (not that I take that to be his only

motive), immediately espoused Mr. Mears's cause. The notion of that 'magnificent casting' being unsound was ridiculous; any thing rather than that: the composition must be wrong, and if wrong it must be my fault; the hammer was probably too heavy, or the buffers wrong, or the bell too tight in the collar—'Did not this journal always protest against that? And now at last it has clearly cracked the bell.' And so forth. Then came Mr. Mears's action, in which his counsel made a speech, and then made an end of the business without any damages, and without getting, and being expressly refused what Mr. Mears had been fighting for throughout, viz. a retractation of my statement that *his bell would never have been certified if the holes in it had not been concealed.* And as he had to give up also another thing, which I was certainly flattered at his contending for, viz. an engagement from me not to publish my version of the affair, I shall now take the liberty of doing so.

When he tendered for recasting the bell in 1857 we heard no more of his objection to the referees, by which he no doubt knew that he had lost the casting of all the bells in 1855, and had thereby set up a formidable opposition to the almost monopoly which he had enjoyed for years. He was willing even to accept the design of the bell from me—a much greater interference than had been proposed or contemplated in 1855. The composition, which he has since pretended that he objected to, was not arbitrarily prescribed by me, but was inserted in the contract with his full concurrence, and more than concurrence; for I asked him, when he brought me the draft contract and proposed some alterations, whether he wished to make any in the composition of the old bell (which was the same), and he answered No, and that it was about what he should use if left to himself, and that the metal would be all the better for being melted again with the addition of some new. On another occasion too, he spoke to me of the bells of one of the other founders being generally too soft, as they were;

and even at his trial, where he had prepared for a lecture on bell-founding to the jury, by casting some thin bars of different compositions, his counsel did not venture to ring them without admitting the superiority of tone of the one nearest to the prescribed composition. The trial stopped before breaking point; and as not one of the bars was of the actual Westminster composition, the breaking experiment would have proved nothing—except that he was afraid of making a fair one. But independently of all this, do Mr. Mears and his friends expect to convince anybody that he, being of sound mind and understanding, deliberately signed a contract to make a bell worth 2500*l.* of a metal which he even suspected to be too brittle, when the same contract provided that the referees might try it as they pleased with a clapper of 7 cwt., and if it cracked in the trials (as the former bell did), he was not to be paid for it? That he had discovered it was too brittle, and that his friends at the Westminster palace had also, long before it cracked, I have no doubt; for we learned from his counsel's speech, that they knew both that and some other things about it, of which the referees were never informed. But it is now known also, that the reason why it is too brittle is, not that it is of the prescribed composition, but *that it is not*, at any rate in the sound-bow, which is cracked in six places already.

Still, as the prescribed composition contains rather more tin (which produces the hardness, and brittleness and sonorousness of that alloy of copper) than is usual in modern bells, I will give the reasons why it was adopted; although I should have no more objected to Mr. Mears altering it a little, if he desired, than I did to Messrs. Warner doing so in the Doncaster church bells, which were cast under my direction exactly at the same time, because they complained that that metal is so hard to cut for tuning.

First then, we found in the experiments of 1855, what Mr. Mears admitted at his trial, that increasing the proportion of tin up to $\frac{1}{3}$ of the copper sensibly improved the

sound, and that the difference between anything near that proportion and the 4 to 1 composition, which Messrs. Warner then used, was so great as to put that soft metal out of the question. Next we found that 3 to 1 was the turning point between a distinctly crystallised metal with a glass-like or *conchoidal* fracture, and a strong metal not brittle; and that 22 to 7 *twice melted* (which it was stipulated that this bell-metal was to be for other reasons also) was perfectly safe. At the same time, Dr. Percy, of the Government School of Mines, was kind enough to analyse for us some bits of Old Tom of Lincoln and some other old bells, which Mr. Taylor and I happened to have; and the proportion of copper in them was barely $\frac{3}{4}$ of the whole; and the published analyses of some great French bells which were melted into cannon in their first revolution give even a higher quantity of tin: in short, the Westminster $\frac{22}{7}$ is not a less, but a greater proportion of copper than was given by any of those analyses. Several authorities in books give even 3 to 1 as the best composition for large bells.

There was therefore every possible *à priori* reason for being satisfied that the $\frac{22}{7}$ mixture was a perfectly safe one, if it was only soundly cast; and the same conclusion is amply confirmed by experience. For there are the Westminster quarter-bells themselves, of the same composition; and though they have not been long at work, having being stopped by the secretaries of the Board of Works out of sympathy for the hour-bell when it cracked, anybody can tell by filing them that their metal is totally different from the brittle sound-bow of Mr. Mears's bell. Several other bells of various sizes have now been at work, for three or four years, both as ringing and clock bells, of the same composition. Moreover it happened that the smallest quarter-bell was at first cast rather too thin to sound the proper note, and consequently had to be broken up and recast; and all Messrs. Warner's smiths and I tried in vain even to crack it with their largest hammers, and it was only

broken at last by laying it down and breaking through the thin part from the inside. It is evident therefore, that this pretence of the prescribed composition being too brittle has no foundation whatever, either in the history of old bells or experience of new ones, and was only invented *ex post facto* in the hope of withdrawing attention from the miscarriage of the casting.

A new design, or section, or *sweep* (as the bell-founders call it), had to be made for this second bell, because it was of course intended to be, this time, of no more than the proper thickness; and the diameter was consequently reduced from 9 feet 5½ inches to 9 feet in order to reproduce the same note, a rather sharp E natural, to agree with the quarter bells which had all been cast then. I also made an alteration in the shape, which was an evident improvement in appearance, and I think it also produces a better sound. I shall describe hereafter what I now consider the standard pattern for bells, which again is slightly different, and ought strictly to be called the Doncaster pattern, rather than the Westminster, as the bells of Doncaster church were the first peal made from it. The Leeds bell and the recast 3rd quarter bell at Westminster are also from that pattern: not that an ordinary observer would perceive any difference in the shapes of all the five bells now, though the difference of the first Big Ben from the second was visible enough. The height was reduced to 7 feet 6 inches, which will save an enormous expense in taking up a new bell, as I have already described at p. 351. The sound-bow is 8¾ inches thick, and the thinnest part, near the top, 3 inches. The note came out exactly in tune with the great quarter bell, and two of them would have required tuning in any case, to make them agree with the other two, and so that part of the business was at any rate successful, and to secure a new bell of the proper note again there is nothing to do but to copy this one exactly in shape and thickness.

The bell was cast on the 10th of April 1858, not in my presence; nor had I anything at all to do with it, beyond

suggesting the mode of blowing in the hot air to dry the mould. Mr. Mears told us that 10 tons of the metal were in one furnace for 22½ hours before the casting, and the rest for different shorter periods; and that it took 20 minutes to fill the mould, into which the metal was run through open channels from the furnaces. I leave those who have experience in large castings in bronze to judge how far those unusually long periods for both operations are likely to have affected the result. The bell was taken out of the mould, it was said, on the 24th of April; but neither of the referees had notice that it was ready to be seen until the 10th of May, although I had particularly desired Mr. Mears, both before and after it was cast, to let me know as soon as it was ready, and he had promised to do so. What was doing in that interval of 16 days, his counsel has been kind enough to tell us. I went there immediately, and Mr. Taylor went a few days afterwards. When I first saw it, the bell was 'trimmed' (the meaning of which he has also told us), and hung with a light temporary clapper for sounding it.

I examined it carefully all over, specially with the object of looking for holes on the surface, which are the only visible indications of unsoundness, though it may exist without them. I could find none, for the very good reason, that they had been filled up with the cement of resin and bellfilings, which Mr. Mears's counsel described as the regular and proper thing. He also gave me a piece which he said had been cut off from the sound-bow, where the hot air had been blown in, and the piece was very good. If the whole bell had been like that, it would have been in reality 'the magnificent casting' which it appeared to be when trimmed up to 'make it look better,' as we learnt from the same candid exposition. I do not mean to say that it ever approached the quarter bells, or even the first great bell, in smoothness of surface, or what is called cleanness of casting: but that has nothing to do with internal soundness. At the same time it should be known

that a smooth and even-surfaced bell is better than a rough one: small bells are known to be improved in tone by having their surface turned. For that reason too, ornaments on the surface are objectionable, and I refused to allow any, except in very slight relief and near the top of the bell.

I heard it struck with the light clapper at the foundry, and the sound was good as far as it went, and free from that peculiar buzz which it acquired afterwards, and which some persons fancied was from metallic contact with the iron collar: a theory to which there is one rather strong objection—that there never was any such contact, seeing that the collar was packed with 'rope-gasket' between it and the bell top, as the people who wrote in the newspapers about it might easily have ascertained if they liked. I have no doubt that the buzz in both the bells (for the first had it still more), was from that natural internal crack which I have spoken of in the first, and from the external cracks in the brittle surface of the second, which probably began long before they were accidentally discovered. It is clear that a bell does not acquire the well-known sound of a cracked bell until the continuity of the metal is completely destroyed, that is, until there is a crack right through. Indeed, Professor Tyndall reports to the Board of Works that the 6 cracks in this bell have not yet affected its tone. I can understand a person of little or no experience in bells not perceiving the jarring of the cracks when it is struck with the full force of the clock-hammer. But it is curious that the lighter it is struck the more sensible the defect is; as perhaps Mr. Cowper and his advisers will learn by the time they have made that alteration of the clock by which they expect to make a large cracked bell speak like a smaller sound one. Porosity has a somewhat similar effect to a crack, though distinguishable from it. Some people will have it that Tom of Oxford is cracked: I am pretty sure it is not: the large holes visible on the surface (the model of which Mr. Mears, or Mr. May the engineer for him, produced in court as a proof of the unimportance of

holes in bells) are quite enough indication of unsoundness to account for the unparalleled badness of the sound.

The bell was sent to Westminster on the 31st of May, 1858. The next day I was surprised to find that it had been painted (I do not mean with oil paint, but with some wash containing muriatic acid) a sort of bronze colour. Some persons thought this rather a suspicious proceeding at the time; but although I told Mr. Mears I wished he had let it alone, I did not think it necessary to make him clean it off, because I believed that Mr. Taylor and I had already seen the true surface of the bell at the foundry. But he gave us a little more information about this at the trial, which of course is to be received as credible, so far as it is a confession of one of his own intended witnesses. It appears that the person who suggested this washing or bronzing operation to Mr. Mears, and did it for him, was Mr. Jabez James, who made Sir C. Barry's clock hands; and that it was done, like the filling up of the holes, 'merely to improve the appearance of the bell,' by hiding some bright places where 'fins' or excrescences had been cut off.

This was not the only service which was confessed, first in a letter from Sir C. Barry himself to the Board of Works, and afterwards by Mr. Mears's counsel, to have been rendered to the bell by this same Mr. James, and the clerk of the works there, Mr. Quarm; for it was they who filled up, not with resin but with zinc, another hole, which was also found by Mr. Dent's men, much larger than those first discovered ones which Mr. Mears's admirer, the sub-editor of the *Times*, described as being 'no bigger than coffee-beans,' and therefore quite insignificant. This was an internal hole or blister, of which the shell was accidentally broken in by the chains in hoisting the bell, and these gentlemen quietly filled it up with zinc, and never said a word about it either to the referees or the Board of Works—until it was found out—'because they knew it was of no consequence.' No doubt too they knew it was of no consequence, and indicated nothing as to the soundness of the bell, that from the

bottom of that large hole there were other small ones running deeper. And we know that they all think nothing more of the porosity which is now visible on cutting into the bell, even where it is apparently sound. It would be rather interesting to see a bell cast at Whitechapel (if such a miscarriage ever happens there), which Mr. Mears and his friends do really consider unsound.

The great bell and the four quarter bells were all tried together on the 18th of June 1858 by the referees, with the assistance of Mr. Turle, the organist of Westminster Abbey, and various other persons. There were some small *open* holes in the top of the 3rd or E quarter bell, and it was also thought by the musical judges inferior to the others in tone, as I have no doubt that a porous bell always would be found, whenever there was an opportunity of comparing it with sound ones of about the same size, which unfortunately there is not with a single very large bell. Moreover, I had learnt from the breaking up of the first great bell and other castings, that external porosity is an almost certain indication of something worse within. The aforesaid Mr. Quarm and Mr. James being present, I asked their opinion of the bell, merely as a question of casting, and they both thought that it was not one which ought to be passed. Mr. Mears was also present, and notwithstanding his conviction of the insignificance of holes, he did not say a word to save Messrs. Warner's bell from condemnation. No doubt he thought they had been very negligent in not 'trimming' it properly, and deserved to suffer for it.

This concurrence of Mr. Mears and his two supporters at the rejection of Messrs. Warner's bell with smaller holes than his own, and in a much less important place, was naturally felt by his lawyers as a dilemma, which, to say the least of it, required explanation; and this was the explanation hit upon:—Inasmuch as the great bell was twice as large as the condemned small one, the holes in that were larger in proportion, it was said, though they were absolutely smaller. They were not so in fact, but

never mind that. Moreover the holes are on the soundbow of the great bell, but were near the top of the other; but never mind that either; for this plausible piece of nonsense admits of an answer not to be affected by any amount of counter-swearing as to the relative size or position of the holes. For if this new theory of metallurgy is to be adopted, we must adopt a new table of specific gravities to suit it, which should be called the Westminster table, indicating the various proper densities of the same metal according to the size of the mass that it belongs to; and before a piece of any casting can be pronounced sound or unsound, we must be informed whether the mass was 100 or 10,000 times as large as that. I wonder what Lord Rosse would say to a 4 ton speculum, which the founders and their friends insisted was a good one because it had only holes in it not quite 1000 times as large as in a good one of 9 lbs; or whether large guns are allowed at Woolwich to be twenty times as porous as small ones.*

There was another remarkable proposition respecting porous bells stated for Mr. Mears in court, and previously by the aforesaid Westminster clerk of the works in my presence. He said, 'you may have fifty bells cast before you will get a better:' a pleasing prospect truly, considering that we have hitherto had a great bell to cast every two years since 1855, and have not yet got a sound one. The other way of stating the same proposition was, that all large bells necessarily have holes in them, and that they cannot be cast without; though Messrs. Warner's large bell had none, except near the top from the accident I have already mentioned. However, as Mr. Mears instructs his counsel to tell the public that he considers it impossible to

* It should be understood that in all these copper alloys there is some porosity; but in good metal it is only visible with a magnifying glass, and I need not say that is not the kind of porosity I am talking of. There are above forty holes in the surface of this bell, varying from $\frac{1}{10}$ to $\frac{1}{4}$ inch in diameter; much less than that, according to my experience, would be an infallible indication of still more porosity inside, and every cut that has been made reveals more of it.

cast bells without holes, and that it is the regular thing at his foundry to stop them up with resin, I am not the least disposed to question it, or to believe any longer that this bell is at all worse than he himself expected it to be when he took the contract. Indeed it is not so bad as the York bell, except for the unhomogeneousness. I cannot speak of the composition of the Mears one, but I shall be very much surprised, from the sound of it, if it is not found to be equally full of holes whenever it comes to be thoroughly examined; and the Royal Exchange clock-bell was more porous and still worse in sound than this. To be sure, it would have saved a vast deal of trouble and expense if he had only told us all this before he got the contract, instead of two years afterwards. And I do not think anybody would have guessed it from the letter which he wrote to me after the casting of the bell, saying that he 'had 'no doubt we should have a first-rate casting, without the 'beauty-spots of the former bell.' However, in future it will be a fully understood condition of his contracts, that holes are to be allowed, provided they are no bigger than those in the Oxford bell; and that an excess of tin or deficiency of copper in the sound-bow is also to be admitted as a common and unavoidable incident in casting, and is no ground for rejecting a bell.

I was curious to see how the other founders would take this public declaration of the impossibility of casting homogeneous and solid bells, and whether they would agree that resin and bell-filings are as good as solid metal. Messrs. Taylor of Loughborough wrote to me, and also to the *Times* to protest against those statements and some others, which they considered a reflection by Mr. Mears on them and all the other founders. *Their letter was not printed;* and no wonder, seeing that the *Times* had vouched for the soundness of 'Mr. Mears's magnificent casting,' even after the discovery of its defects had begun. Messrs. Warner took a different line; and their letter was printed, *and only my answer to it suppressed.* They thought it was a good opportunity

to lift up their heels and insinuate that I had cracked their bell; and they were content to accept in silence Mr. Mears's statement that the casting of large bells without holes is impossible, though they have themselves proved it to be possible. It would doubtless be very convenient for them if they could ge[illegible]e public to believe that porosity is unimportant, if not [illegible]able; for then, whenever they have the bad luck to cast unsound bells (as anybody may sometimes), they would escape having to recast them into sound ones at their own expense, as they did the condemned quarter bell, and another which I had condemned before. There will be no difficulty in getting sound and good bells if people will inexorably reject bad ones; as they always may if they will make proper contracts, and enforce them rigidly. Mr. Mears may decline to cast on these terms if he thinks them impossible; but there are at least two other founders who will not decline.

When his bell was sent to Westminster, he begged that 'it might not be knocked about with the clapper as the 'other was:' rather an odd request to make for a thing whose only business in the world is to be knocked about with a clapper. However, in consequence of the complaints of persons in the neighbourhood about the noise of ringing the first bell for a quarter of an hour a week, Mr. Mears's request was unfortunately complied with. If it had not, we should have learnt the good qualities of his bell before instead of after it was hung; for I have no doubt that an hour's ringing with the clapper would have cracked the brittle crust of the sound-bow, and that would have led to the discovery of the other defects, as it did afterwards.

The bell frame. The bells were taken up the tower soon after the recast E bell was delivered by Messrs. Warner, and the great bell was hung soon after and tried in its place with the clapper in November 1858. The bell frame is made of wrought iron beams resting on cast iron struts standing on the tower walls. I had told the clerk of the

works long before it was finished, that it would require some diagonal braces to resist the oblique action of the great clock hammer, which must reach the frame somewhere. But the Westminster architects and engineers knew better: they were convinced that the stiffness of the joints would be enough. It will not do for them to say they contemplated the bell being hung differently, for the mode of hanging had been settled since 1856, and Mr. Jabez James had made the collar ready for the first bell, and also the shanks of the clock hammer, which was then too expected to be not 7 but 13 cwt. The first blow with the clapper, before any clock hammer was tried, settled the question of the frame; and as the reporter for the *Times* then said, 'the necessity for increased supports was at once apparent.' The attempt to account for not only the shaking of the frame, but for the defective sound of the bell, by the rigidity of the hanging, was a later invention; which rather unluckily was not propounded until after the bell had been loosened, in the vain hope of thereby preventing the vibration of the frame. And it is an amusing specimen of infallibility, that when the *Times* was loudest in praise of the sound of the bell, it was screwed up the tightest; and when they and their followers declared it was spoilt by being screwed up tight, it was much looser in the direction of the clock hammer than any church bell in the kingdom is, or can be, when hung in the usual way. But whatever else may be effected by getting stories of that kind published, they will not strengthen bell-frames; and so Sir C. Barry and his men at last set to work to do it with iron braces instead of newspaper articles, and finished it in five months, doing then as much more than was required for the purpose, as they had before done too little. However there is no great harm in that, beyond the waste of money, which is probably a small item in the two millions and a half spent there.

The Clock-Hammer. Mr. Mears's anxiety that his bell 'might not be knocked about with the clapper before it

was hung,' naturally extended to the clock-hammer, which he requested might not be above 4 cwt. I should have thought he must know that it was ridiculous to expect a hammer of 4 cwt. to answer, when the clapper of 6½ was evidently not too large. Clock-hammers always have to be heavier than clappers, to make the bell sound properly (which 9 out of 10 do not, because the clocks are too weak to lift them), inasmuch as they only fall a few inches, and are checked by a buffer or spring to prevent them from lying on the bell, which would spoil the sound; though they often do that also from the springs wearing out or getting loose. However, to satisfy Mr. Mears, I began the trials with a 4 cwt. hammer, capable of being increased by 'shifters' to nearly 7. It is not worth while to go through the details of the experiments, which were carried on for several days. Mr. Mears could not help admitting that neither 4 nor 5 nor 6 cwt of hammer would produce a sound equal to that of the clapper, with even a higher lift than we have got. Beyond a certain point, I may observe that an increase of lift does no good, though of course the force of the blow increases as the square root of the lift, except so far as it is reduced by friction and the inertia of the shanks and levers, as it is very materially here. There are always some particular weight and lift of hammer that suit a given bell better than any other, and they can only be determined satisfactorily by experiment, or by previous experience in a similar case, as they vary for bells of different shape, thickness, composition, and soundness of casting.

It was at last agreed, after trying them both near and at some distance in the Park, that a hammer of about 7 cwt. lifted 13 in. obliquely, or at right angles to the face of the bell, was better than any other; and the permanent hammer was cast and the levers adjusted accordingly. Mr. Jabez James, who made it, stated in a paper read at the Civil Engineers', that it was 6 cwt. 3 qrs. 10 lbs.; and indeed the size proves that it cannot be more. On account of its being fixed more obliquely than usual, the actual pressure of the

hammer on the bell or the buffer-springs, when at rest, is under 5 cwt.; or, what is only another way of stating the same thing, the 13 in. of oblique lift are equivalent to little more than 9 of vertical lift; and 9 in. fall onto the buffers leaves less velocity and momentum of the hammer on the bell than if it fell 7 in. without any buffers. A clapper has a long run at the bell and has no buffers. A ball of 7 cwt. was dropped onto the first bell to break it up, not 13 *inches*, but 24 *feet*, perpendicular and free, and it bounded off without even cracking the bell, and a 24 cwt. ball had to be used; which is another pretty strong proof of the toughness of that composition when cast soundly.

The Cracks. The clock began to strike in July 1859, and Mr. Dent's men found the two principal cracks in the bell on the 28th of September; and in exploring them with a steel pricker they made the first discovery of the filled up holes, three of which were coincident with one of those cracks, and a cluster of others near it. No other defect was then discovered or suspected, except the unsoundness indicated by those holes on the surface; for although a great many holes as large as most of these might exist on the mere surface of a bell of that size without doing much harm, a very few such holes on the surface are a certain indication of there being many more below the surface. And accordingly the very first cut that was afterwards made into the bell, even at an apparently sound place, disclosed a state of internal porosity worse than any that appeared on the surface.

Besides this, the position of much the largest crack of all proved that it had come from some internal defect, and not from the mere force of the blow; for instead of being exactly opposite to the hammer, or at a place of greatest vibration (as the sub-editor of the *Times* with his usual accuracy asserted), it happens to be exactly at a place of *least* vibration (as Professor Tyndall specially noticed in his report to the Board of Works), where no bell in the world ever cracked or can crack except from congenital

unsoundness. And therefore, when I heard of the discovery of the holes, and the cement in them, and the cracks near to and coincident with them, and the largest crack at a point of least vibration, I had no hesitation in publishing my opinion that the bell was 'congenitally unsound' (and so it turned out to be, even more than I then supposed), and that the porosity was the cause of the cracks, which turned out wrong, because there was something worse.

I immediately wrote to inform the Board of Works of this pleasant discovery, and they immediately acted with their usual energy and intelligence; and I may add, with the usual consideration of Government Boards for people who have been doing for them for years, gratis, the work which they were confessedly incompetent to do for themselves. The first thing they did was to order Mr. Dent to stop the striking of all the bells. I told them there was no reason for stopping the quarters; but they knew better: or perhaps the pleasure of stopping anything was irresistible. I only wonder they left the clock go at all. They did lock the clockmakers out of the tower and stopped the completion of some things which another fortnight would have finished, and only allowed the men to go up once a week to wind the going part under the supervision of their own clerk of the works. And neither with that escort of their own officer, nor without it, could I get leave from these potentates of the Board of Works (Mr. Fitzroy himself being then ill and dying) to see the cracked bell at all for more than six weeks, notwithstanding the pendency of Mr. Mears's action, whose object of course was to prevent his bell being proved to be unsound, and who resisted as far as he could every proposal to have it fairly investigated. It will be seen presently that if the Secretaries of the Board had acted as any man of sense would act in an affair of his own, they might have learned that it was unsound in a week after it was cracked; and I need not say what they ought to have done in that case. It took nine days more after I first saw the bell, to persuade them to have Mr. Jabez

James's blue wash rubbed off, and the true surface of the metal exposed by cleaning it with sulphuric acid: after which I counted 40 distinct holes, from $\frac{1}{16}$ to $\frac{5}{8}$ inch in diameter, besides several clusters of smaller ones, which had all been filled up either with the resin and bell-filings, or the zinc before described. And it was not for two months after the discovery of the cracks and holes and cement, that I was permitted to cut off from this cracked and porous bell of 13½ tons, a bit 'not exceeding an ounce,' to be analysed; and even after it was analysed and proved to be bad, the Board of Works still absolutely refused both my application, and the suggestion of their own examiner, Dr. Percy, that the bell should be further cut into to the depth of the cracks at least. One might almost suppose that they hoped the cracks would heal up of themselves if they were only left alone; and perhaps that is the true reason why nothing has been done yet towards getting a new bell, which might easily have been made and at work again by this time.

At last I got the 'bit not exceeding an ounce,' and Dr. Percy got another bit, and Mr. Mears another, all cut from one of the 'wires' or ornamental rings just above the sound-bow, and at a place which appeared sound externally. The cuts extended about 1½ inches, and when they were made they displayed internal porosity for nearly the whole length; thus confirming the judgment which I formed as soon as I heard of any superficial holes being discovered. But I immediately saw that there was something worse still, and that the composition had altogether miscarried. And the several analyses, of one bit by Messrs. Johnson and Matthey the assayers, and of the other by Dr. Percy, amply confirmed that view. But first I should mention that, besides these pieces from the sound-bow, Dr. Percy had another bit cut from near the top of the bell; and that piece does not deviate materially from the prescribed composition, but does fall 5 per cent. short of the minimum specific gravity (8·8) prescribed by the contract, while that of Messrs. Warner's bell slightly exceeded it, both at the top and the bottom.

The analyses proved that, instead of the bell being $\frac{22 \text{ copper}}{7 \text{ tin}}$ throughout, according to the contract, one of the bits from the sound-bow is only $\frac{19.4}{7}$, and the other $\frac{19.9}{7}$, while the bit from the top is $\frac{22.3}{7}$. In other words, the metal on the cracked sound-bow wants from 33 to 46 lbs. more copper to every 1 cwt. of tin, to make the bell either homogeneous, or of the prescribed composition. So after Mr. Mears and his allies had been labouring for two months to get up proofs, and were evidently going to swear, that the bell had cracked because the prescribed composition was too near the turning point of brittleness, it turned out that he had himself contrived to make it very much beyond that point, and so brittle that it was quite certain to crack. Dr. Percy also sent to the Board of Works by way of contrast, the analysis of bits from the top and the bottom of Messrs. Warner's bell, which was nearly homogeneous and deviated very little anywhere from the prescribed composition. It will not avail Mr. Mears to say that the bits which were analysed, were only from the 'wires,' and not cut out of the body of the sound-bow; for it was his own fault that they were not: he was asked to concur in an application to the Board to cut farther after those cuts were made, and he refused. Moreover, other bits accidentally chipped off the edge of the bell show just the same brittle kind of fracture, and the sound-bow has been tried with a file all over and is everywhere as hard as where the bits were cut off, and much harder than at the top, where the composition appears to be right, though the specific gravity is wrong.

Nobody can have had any real doubt after this discovery, whatever he might choose to say, that the miscarriage in the composition, and the consequent brittleness of the sound-bow, was the cause of the bell being cracked in five or six places. But it must be added, that if the holes had

not been concealed, and if Mr. Mears had resisted the condemnation of the bell on that account, as he very likely would, and had brought people to assure us that porosity was of no consequence in his bell, whatever it might be in Messrs. Warner's, I should at once have dared him to cut into it to the depth of the holes, as I did when I condemned a previous bell of Messrs. Warner's; and we know that the very first cut would have revealed two things, as it did a year and a half afterwards:—first, the still greater porosity below than at the surface, and secondly, this other and more fatal defect in the composition. And so it is the fact, that although the holes did not cause the cracks, the defect which did cause them would have been discovered if the holes had not been concealed; or else the condemnation of the bell for porosity would have settled the question without further discussion, and it would never have been hung to crack.

Mr. Mears's action. When I first announced to the public that holes had been discovered in the bell, filled up with an artificial cement, and that the referees had no idea of the existence of such holes when they passed the bell, Mr. Mears replied in the *Times* with '*the most unqualified contradiction*,' and enforced it with the statement that he was going to refute the calumny, and vindicate the soundness of the bell, by an action. I have no hesitation in saying now, what I suspected before the bell was cut into,—that if the Board of Works had done their duty, and had a complete examination of the bell made at once, (which, according to Mr. Cowper's own account, they have not done even yet), no such action would have gone on, and the tables would have been turned on Mr. Mears. As it was, he was persuaded by his advisers, after he knew I had got the analysis, to retire without a verdict, and without getting, but on the contrary, being distinctly refused, the retractation of that statement which both he and his counsel declared to be 'the sting of the libel,' viz., that the bell got passed by the holes being concealed. But his persistence

up to just that point did something more. His counsel had to expand his 'unqualified contradiction' of my published statement about the bell into an explanation of Mr. Mears's theory and practice of bell-founding and bell-trimming. And in so doing he had to make the following remarkable avowals:—

1. That there were holes visible in the soundbow of the bell when the mould was cleaned off.

2. That they were filled up with resin and bell-filings before the referees saw it, 'to make the bell look better.'

3. That it is the regular practice at his foundry to do so, if he or his men consider the bell a sound one in spite of the holes.

4. That he considers the still larger holes in the Oxford bell, of which holes he produced a model and map, the proper measure of what ought to be allowed as insignificant porosity.

5. That the Westminster bell is also porous below the surface, in a place apparently sound, viz: where the pieces were cut off.

6. That there is at least one internal hole, besides; viz. that large one which Mr. Quarm and Mr. Jabez James filled up with zinc, with small holes running out of it.

7. That it is impossible (*i.e.*, of course, for him) to cast bells without holes as large as those in proportion to the size of the bell.

8. That 'there is a slight excess of tin at the bottom of the bell;' that slight excess being such that 1 pound or 1 cwt. more of copper is required to every 3 of tin to bring it to the prescribed composition, or to make the bell homogeneous.

9. That this too is nothing uncommon in Mr. Mears's experience, and, in his opinion, is of no more consequence than the porosity.

Such was the end of Mr. Mears's 'unqualified contradiction' and determination to go on for either a retractation or a refutation of my statement, that this unhomogeneous

and porous and brittle bell got passed by the holes being filled up with his resin and bell-filings. If any one is surprised at a bell-founder and his counsel going into Court to make such confessions as these, he must remember that they had left themselves no alternative, except the still more awkward one of avowing that this bell was worse than Mr. Mears had ever made before—more porous and more unhomogeneous—that he had never stopped up holes before, but did so this time for fear the referees should reject it. Such being the necessary alternatives if he was to say anything, perhaps he would have done more wisely to say nothing, and be content with the letter I wrote to him and published, as soon as I had got the analysis,—saying that I was now satisfied that the holes had not caused the cracks, although they would certainly have caused the rejection of the bell if they had not been concealed from the referees, as he after all confessed they were: the cracks being really caused by a still worse defect, of which I had no suspicion till I saw the bell cut into. It is only necessary to add, for the information of those who were naturally surprised at it, that the withdrawal of the plea of 'justification' was only the legal consequence of the discovery that the cracks were due to a different though a worse defect in the bell, than that to which I had attributed them. For it is a rule of that mysterious branch of common law, called 'special pleading,' that if any fact alleged in a so-called libel turns out different from, even though it may be infinitely stronger against the plaintiff than what was alleged, it will not support the plea of justification. I understand that the folly of this rule has been publicly remarked on by judges, but it still exists, probably waiting for a more sweeping reform some day.

Official report on the bell. Mr. Cowper, the present Commissioner of Works, was asked for an account of the real state of the bell in the House of Commons, on the 7th of March, after he had received the reports of Dr. Percy and Dr. Tyndall, who had been appointed to investigate it.

His answer was that there were 5 or 6 cracks in it, and that they had been caused '*either* by the hammer being too 'heavy for the tenacity of the bell, *or* the bell being too 'brittle for the hammer, but he could not say which.' This profound scientific discovery was received with the laughter it deserved, the House of Commons probably thinking that any man in the street could have told them about as much as the Commissioner of Works appeared to have learnt from the reports of his two scientific referees. It certainly is curious with what ingenuity the official mind contrived to pick out from the whole of these two reports, just that one sentence, which, professing to enuntiate an important practical conclusion, disclosed absolutely nothing, and to suppress altogether the conjecture in one report, and the positive statement in the other, of the really fatal defect in the bell, and the ascertained cause of it. It may or may not have been a very scientific proceeding to report at all upon a casting of compound metal upon conjecture, when it would have been so easy to make it certain by analysis, which I had got, and of course Dr. Tyndall might have got also, long before his report; but still he did conjecture, and rightly, from the appearance of the cut into the bell, 'that, owing to the imperfect mixture of the constitu'ents, or through a defect in cooling, the external portions 'of the soundbow may vary in composition and tenacity, 'from the average composition of the bell'; and besides that, Mr. Cowper had received Dr. Percy's report and analysis positively confirming that view of the miscarriage of the casting, when he told the House of Commons in effect that nothing at all was known of the composition or quality of the bell.

This was bad enough, but it might be nothing worse than ignorance of the subject. Mr. Cowper might have glanced over the reports to find something that looked like a practical conclusion to quote in answer to the question, and he would very naturally not perceive as quickly as the laughers in the House of Commons did, that he was only

talking nonsense, by quoting so much and no more than that one sentence. But he had lost even this poor excuse before he was put to the question a second time, on the 25th of April. It is a coincidence worth mentioning, that just after he had notice from a friend of mine that he intended to ask for some more specific information about Dr. Percy's report, Mr. Cowper wrote to me for the first time, asking a question about the clock, on which his Board had had my opinion three times already, and also professing to want my opinion about the bell, which was equally well known, and which it was evident to me then, and more evident since, that he had no intention of following. However I answered his questions, and also told him that he had mis-stated the effect of the reports of his own examiners on the bell, and that he ought to correct it, as I had reason to complain of the failure of the casting being thus suppressed. What then did he do when the question was asked in the House a few days afterwards? *He still withheld Dr. Percy's report*: evaded answering the question about the analysis and the brittleness of the bell; and took upon himself to say instead, that, 'Dr. Percy did not consider his analysis sufficiently conclusive to give a definite judgment on the chemical composition of the bell generally.'

If anybody can believe that this second and more distinct misstatement of the report was a mistake also, after reading what I am going to quote from the report itself, by all means let him give Mr. Cowper's honesty the benefit of the doubt, though it must be at the expense of his understanding. Dr. Percy begins (after merely formal matters) by giving the analysis of the two bits from the top and the bottom of the bell, and contrasting the latter of them with the composition prescribed by the contract. And then he says, 'a difference of even 1 per. cent. of tin, which is much less than the actual difference (see p. 374), 'would, I have no doubt, occasion a sensible increase in the 'hardness and brittleness of the metal: so that the metal of

'the lower part of the bell should be (as it is) harder and 'more brittle than the alloy prescribed;' although, as he next explains, it is of course impossible to infer the composition of even the adjacent parts, and much less of the entire bell, from the analysis of small pieces from the outside, when it is once proved to be unhomogeneous. I dare say the general or average composition is right enough, as it could hardly be wrong without deliberate intention and for no object, tin being quite as dear as copper. The defect is, that the most important part of the bell *differs from* the average or proper composition. And if this was not enough to enable Mr. Cowper to understand that the defect of the bell is that it is unhomogeneous, and excessively brittle on the sound-bow, because it deviates from my composition, I should like to know for what purpose he conceived Dr. Percy to have added the analysis of the bits from the top and bottom of Messrs. Warner's bell, with the remark—'it will thus be preceived that the 'composition of the former bell appears to have been more 'uniform than that of the present one.'

And let me ask one more question: if Mr. Cowper really has been burning with desire to have 'a definite judgment on the chemical composition of the bell generally,' why has he not got it long ago? Here has the bell been cracked and silent for 9 months, and if his own account is to be believed, the Commissioner of Works is yet wholly without information on what he conceives to be the essential thing for him to know, before he can decide what ought to be done with a porous and unhomogeneous and brittle and six-times cracked bell. And he has the less excuse for this neglect of what he thus admits ought to have been done, because everybody who has given any opinion on the subject, so far as I know (with the single exception of Mr. Mears, who has twice done his best to prevent it), has told him that the bell ought to be cut into at least to the bottom of the cracks: with different objects certainly; some people thinking the bell would be thereby

cured, and others being sure that its unsoundness would be thereby confirmed.

On the 4th of June, Mr. Cowper had a third opportunity of enlightening the public on the real state and prospects of the bell. Still 'the inquiry was not completed.' I can add—not begun; for not one bit more had been cut out of the bell, nor a single hole drilled into it, for the purpose of ascertaining its internal composition. Nevertheless Mr. Cowper had no hesitation in saying, 'it does not appear that 'it will be necessary to abandon the use of the bell alto- 'gether; but as a temporary arrangement' (while it is getting well of the cracks, I suppose, and settling down into a more homogeneous and less brittle condition) 'he 'thinks it would be best to use the largest quarter bell for 'the hours, and the other three for the quarters.' Of course he does not know, and does not think fit to ask the designer of the clock, whether the notes of the bells are suitable for such an arrangement, or whether it would not be necessary to alter the clock to make it strike any chimes at all on three bells, instead of those for which it is constructed on four, and then to alter it back again for the original chimes after his temporary arrangement is terminated on the restoration of the great bell to health.

At last however, he has let out the real reason of all this delay and pretence of investigation, which indeed it was not very difficult to divine before, remembering that a certain Prime Minister, with whom he is a good deal more than officially connected, last year pronounced the striking of the clock a nuisance, and Mr. Fitzroy was desired to ask me if it could not be stopped every evening while the House was sitting. And so Mr. Cowper now says, 'it is rather hard that half the 'county of Middlesex should be informed of the hours 'at the cost of the serious inconvenience of that House.' I do not venture to express an opinion whether those who have paid 6000*l.* for these bells may reasonably expect to hear them. But I am convinced from experience

in other places, and indeed from some experience in the Committee rooms of the very place in question, that, although the striking of a clock may be felt as an interruption for a few weeks while it is a novelty, the loss of the striking is often thought a greater nuisance afterwards. It should be remembered that the House of Commons and the clock were only speaking together for about a month last year. But I suppose we must wait till Mr. Cowper rises into a Secretary of State, or otherwise leaves Her Majesty's public works to be managed by somebody else. Then perhaps at last we may get a great bell cast soundly, after the same number of trials as they had in Paris 180 years ago, and the Westminster clock may at last be allowed to be completed, if it has not been spoilt in the mean time.

P.S. I am just in time before this sheet is printed off to add a rather decisive piece of information. The bell has been at last cut into down to the bottom of not the largest crack. Its depth is already $\frac{2}{5}$ of the thickness of the bell, having no doubt extended from a slight one beginning in the brittle crust, as a crack or a diamond-cut runs on in glass. Besides that, there are even worse holes inside than I expected from the discovery of the external holes: larger by far than I ever saw in any other broken bell metal. One of them has been large enough to stop the crack suddenly where it is three inches deep. And yet further, a piece has been cut off the lip, near the end of another crack, and it is worse than the worst of the three other bits cut off the wires, and quite bad enough to condemn the bell upon, independently of either the holes or the brittleness.

I am far from supposing however, that this discovery—or any other, will make the least impression on the present Chief Commissioner of Works, any more than the recent success of his determination to have the fourth pair of hands fixed by the engineer who made the condemned minute hands, instead of by the clockmakers. I shall not be at all surprised to find him telling the House of Commons again, that, notwithstanding the cracks nearly half way

through, and the holes all over, and the brittleness of the outside, and the miscarriage of the composition, 'it does not appear 'to be necessary to abandon the use of the bell,' or to pay the smallest attention to any advice or opinion he may have received from me about either the bell or the clock.

ON TRYING BELLS.

It is evident that whenever another large bell is to be cast for Westminster, or York, or Oxford, or even smaller bells than those, there will be no security against another failure unless the referees have the means of making a more searching examination of its constitution than they have ever had yet. To be sure we have been told by a great authority, who is never wrong, and can always prove that he said the right thing at the proper time, that the way to get a good bell is to have no interference of referees at all, but 'give your orders to an eminent bell-founder 'who has made his fortune in making bells (sound or un-'sound), and you are sure to have it.' Of course the sub-editor of the *Times* can prove that it was the interference of referees that made the first Westminster bell thicker than their pattern, and the second different from the composition prescribed, and unhomogeneous, and full of holes, and the York bell thicker on one side than the other, and porous too, and the Oxford one still worse, and made the Montreal bell crack in a year, and the Exchange bells have to be recast twice because they were so bad, and the great bell of Paris to be cast three times over, and St. Paul's twice, and then probably unsound, as I have little doubt it is. The fact is that the sound casting of large masses of this compound metal is by no means an easy job, and evidently requires a good deal more management than our 'most eminent bell-founder' knows how to apply, since he declares that it is impossible to cast bells without holes in them, or with any certainty of

their being more homogeneous than the Westminster bell is.

It is true that that declaration is no evidence as to the capacity of the other bell-founders; one of whom, as I have already said, did his best to protest publicly against it, although the *Times* suppressed the protest; and other founders who did not protest have practically refuted Mr. Mears's declaration by casting two 4 ton bells soundly and without holes. Still the difficulty or the risk is so great, and the temptation to conceal or make light of a defect in a large bell is so strong, that everybody except the partisans of a bell-founder must see the necessity for a more and not a less stringent supervision by the referees. But for their interference, the public would now have had to pay for two more unsound bells, which Messrs. Warner thought themselves very ill-used in being forced to recast into sound ones, and which they would easily have found engineers and clockmakers enough to convince a jury of tradesmen that they ought to be paid for, if a jury of tradesmen had been the judges. Neither of those bells was anything like so bad as Mr. Mears's large one, which escaped the same condemnation only in the way I have so often mentioned. Leaving the bell-founders then to discover, if they do not yet know, how to avoid such defects, let us consider what means ought to be used to detect them when they exist.

First of all, it should clearly now be a condition of a bell contract,—and probably not of bell contracts only, that if anything which the referees shall consider a material defect, is *at any time* discovered to have been concealed, the founder shall pay all the expenses of re-casting. Hitherto the founders have been almost invariably their own referees; although we see that two whole peals at the Exchange and four out of the eight bells which have been cast for the Westminster clock have either actually been condemned to be recast, or have only escaped condemnation at the proper time by accident, mistake, or conceal-

ment of their defects. Yet Mr. Mears openly avows that he thinks the bell-founders ought to be the judges, and ought to conceal defects which they think immaterial, even when there are independent referees, to whose judgment the founder professes and contracts to submit: and the *Times* agrees with him. But notwithstanding that concurrence of authorities, I rather think the public will be of a different opinion; and now that they have learnt a little more about the matter, I believe no more porous or unhomogeneous bells, or bells of unequal thickness, or bells spoilt in tuning will *knowingly* be paid for, in spite of all the protestations of the founder that such miscarriages are common and of no consequence. We are at last obliged to begin passing special Acts of Parliament to stop the adulteration of our food, the selling of 200 yards of Manchester fabrics marked 300, and to save our lives from being lost at sea by unsound and untested cables, and there will be much more of the same kind to do yet. But in this comparatively unimportant matter of getting sound bells, the purchasers can protect themselves if they choose by merely making proper contracts and enforcing them, and the first step towards doing it is what I have suggested.

Besides this, the referees, or somebody for them, ought to see the bell as it comes out of the mould (as it is only fair to say that I was invited to go, and went, to see the first great bell, in the north), and not to be kept waiting a fortnight while it is being 'trimmed.' If any porosity is then visible, except perhaps a little at the top, the bell should be condemned, unless it can be proved, by cutting out the whole of it, that it is *only* superficial. I doubt whether there is a very bad bell anywhere, of the proper shape and good thickness, which has not either holes in it, latent or patent, or else some such other distinct defect as I have mentioned; and I certainly never saw a good bell that was a bad casting. Although the York bell has another defect, viz., the unequal thickness, that is not

alone sufficient to account for its tone; the Oxford bell has no defect that I know of, except the holes which Mr. Mears thinks of no consequence, to account for its unrivalled badness: some of the Exchange bells, I have already said, had visible holes in them, and Mr. Mears's tenor bell of old Doncaster church, cast in 1835, which was always thought a bad one, was porous at the lip, of which I have a piece now. The same is the case with old bells of two centuries ago, as I learned in the first peal I ever rang, in which the porous bells were all bad, and the others good.

The more difficult thing is to ascertain whether there is internal porosity; which there may be with an apparently sound surface, as in some places in the Westminster bell, and in the York one, which has a blister already broken in by the hammer, and the same thing happened in the Exchange clock bell. It is evident that the runners and fins projecting from the top and the lip of a bell cannot be relied on as specimens of the metal, either for analysis or porosity; and you cannot take a *taster* out of a bell as you do out of a cheese. Therefore I should now require some broadish lumps, as big as half an egg, to be cast on it in various places round the soundbow, and have them cut off *in the presence of the referees*. If there is any miscarriage in the casting it will be strange if that excision does not reveal it somewhere; and it will not damage the bell as incision would. Such miscarriage will be indicated by porosity visible without a glass, or by the specific gravity being too low, or by the composition being wrong by analysis, or by general appearances of the metal which cannot be described, but which a little experience will enable any competent person to recognise as defective. Bad specific gravity is, in fact only one form of porosity. I shall show what it ought to be in the next chapter. It is true that even this test would not discover such a defect as the non-union of the metal inside the bell; nor do I know what would, except the sound. But I am quite

sure now that any buzz or indistinctness in the sound, which both these bells had, indicates something wrong, and that no bell with such a sound is sound.

As to judging of bells in peals, I cannot too strongly impress upon those who have to pay for them, to take care that they have a distinct judgment upon each bell separately, without reference at first to the question of tune; for as I said before, a set of saucepans or flower-pots might be in as good tune with each other as the finest peal of bells. And it by no means follows that because a man is a musician he knows what bell-metal is capable of, and therefore whether a bell is as good as it ought to be: the only way to determine that is to adopt some bells of about the same size and acknowledged goodness as a standard, as perhaps Professor Taylor condemned the Exchange bells by comparison with the Bow bells of the same size and notes.

It is essential to bear in mind that there is no assignable relation between the sound of a bell and its liability to crack: indeed a bell that is bad because it is too soft is of course less liable to crack than a better one. And therefore merely to stipulate that it shall be rung for a certain time before it is paid for would be rather worse than nothing, unless it is also stipulated that it shall contain the proper quantity of tin. I shall have something more to say on that point under the construction of bells; but with that condition, the test of ringing with a full-sized clapper for a considerable time is a perfectly right and necessary test. The first Westminster bell was cracked, as it deserved, by ringing it for a quarter of an hour a week for 10 months, or only 10 hours altogether, and the second would no doubt have been cracked soon if it had been tried in the same way, and not unluckily escaped the trial (as Mr. Mears requested) out of consideration for the people in the neighbourhood. The German rule appears to be either 24 hours continuous ringing, or a year's ordinary ringing. The first is probably the severest test, and has the advantage of settling the question speedily. As I have said before, a bell on the

Westminster or old scale of thickness or weight for its diameter, ought to bear a tolling if not a ringing clapper of $\frac{1}{40}$ of its weight, and will probably not give out its full sound with less; and certainly will not if the bell is only tolled, and not rung in full swing. Thin bells naturally require lighter clappers, as light perhaps as $\frac{1}{60}$ or even $\frac{1}{80}$ of their weight, and their sound is proportionately weak and bad, except when you are close by; for they seem to sound actually louder than thick ones, when you are near them, and so people are often deceived by hearing them in the bell-foundry.

Most bells improve in tone and get louder for a few years: not, as some books absurdly say and many people believe, by the clapper wearing a broad place for itself to strike on (for then turning the bell to a new place would make it sound worse again, which it does not), but for a very different reason. It is well known that continued hammering or vibration tends to produce a more crystallized state in all metal. I have already mentioned that watches with new balance springs generally gain after a few months vibration, obviously from their becoming more elastic or less soft and yielding. Fortunately there is a limit to this; or else every bell would come to a natural death from its increased brittleness no longer bearing to be struck. Sound bells sometimes do crack capriciously, it is true; but old ones are no more liable to it than new ones, until they have got worn thin in one or two places, which may be materially diminished, by the mode of hanging them which I shall describe hereafter, and still more completely by the more expensive Westminster plan, already described at p. 352. But let me end this chapter by warning people who have to judge of bells against being persuaded that a bad bell will ever improve into a good one, for it will not.

ON BELLS IN GENERAL.

THERE is still less to say of the history of bell-founding than of clock-making. Indeed it is hardly a progressive art at all; for as soon as the right shape and composition are discovered, and the means of making a sound casting, there is nothing more to do. Small bells, probably not cast but hammered, and of gold, are, we know from the Bible, as old as the time of Moses; and some such old bells of sheet copper and even sheet iron are said to have been found at Cologne and in Ireland. The Romans also had them apparently. They can only be very thin, and of a very different sound from our thicker cast bells. The nearest modern approach to them is the Chinese gong, which is made exactly of our bell-metal, but hammered, which that metal oddly enough admits of when it is heated and cooled suddenly in water. Gongs, like thin bells, sound very ill except when you are near them, and have less power than the same weight of metal cast into a bell of a much higher note. The following is the short history of cast bells given in some of the Encyclopædias:—

'The large bells now used in churches are said to have been invented by Paulinus, bishop of Nola in Campania, about the year 400. They were probably

introduced into England very soon after. They are mentioned by Bede about the close of the 7th century. Turketul, abbot of Croyland, who died about 870, gave a very large bell to that abbey; and his successor Egelric cast a ring of six others. Pope John XIII. consecrated a very large new cast bell in the Lateran Church in 968.'

It is said in *Otte's Glockenkunde*, the latest German book on the subject, but one which does not contain much information of a practical kind, that bell-founding flourished in all the monasteries in the 12th century, and that there were travelling bell-founders who went about casting bells where they were wanted. I suspect this practice went on very much later; for it is impossible to believe that there were regular bell foundries in anything like the number of places from which the 'legends' on still existing bells testify that they have come. The great clock-bell on the top of the central tower at Canterbury is said to have been recast in the cathedral yard as lately as 1762. Indeed the carrying of very large bells along the roads of old times would have been a more serious affair than casting them.

The founders of large bells in England have for some years past been very few. The most famous bell-founding family on record were the Rudhalls of Gloucester, who are known to have flourished there from the time of Henry VIII., and some people think still earlier, till about 30 years ago, when they disappeared. They cast the Westminster Abbey and Chester Cathedral bells, and the Magdalen bells at Oxford (of which the large ones are too thin), and a great many others. Farther back the Purdues of

Salisbury seem to have been equally distinguished for many generations. The firm of Watts, Eayres, and Arnold also existed in Leicester and St. Neots for two centuries, and has now merged in that of Messrs. Taylor of Loughborough. The predecessors of Mr. Mears's father at Whitechapel, were Lester, Pack, and Chapman, who made the Bow bells, and those of St. Peter's, Mancroft, Norwich, which are considered the two best peals in England; and before them was Phelps, who recast the St. Paul's bell a second time, because Sir Christopher Wren considered the previous casting by Philip Whiteman, the founder of a good peal at St. Alban's, a failure: the present bell is a bad one, and is said to sound no one note, but a compound of two, viz. A and C sharp. Tom of Oxford was cast by one Hudson in 1680, and far exceeds St. Paul's in multifariousness, being said by the learned to sound no less than 5 notes at once. No wonder it is thought by other people to be cracked. The next most celebrated, but now extinct, founder of this century was Bryant of Hertford, who was also a church clockmaker. There are some nice peals of his at Waltham Abbey, Saffron Walden, and St. Alkmund's, Shrewsbury, a town full of peals of bells both bad and good. He never gave in to the modern heresy of casting thin bells. The best small peal I ever heard is at Castle Camps in Cambridgeshire, made by Dobson in 1827, who lived at Downham, and died in the Charter House; and there is a good peal of eight by him at Finchingfield in Essex.

All these foundries, except the Whitechapel and Loughborough ones, have disappeared, besides some smaller; and a few years ago, the makers of large

bells in England were practically reduced to two, Mr. Mears and Messrs. Taylor, and the business of the latter was very small comparatively. Messrs. Warner's first peal of any considerable size was cast in 1853 for the cathedral at Fredericton (the chimes and clock of which are mentioned at pp. 131, 191), and they copied the bells of St. Andrew's, Holborn, for it, for the reason I have already given at page 350. Their success with the Westminster quarter-bells, and the Leeds bell, and the peal at Doncaster, and the sending of Mr. Mears's Exchange bells to be cast again for the third time by Messrs. Taylor, have established what is called in railway matters 'a wholesome competition,' which would have been still more effective but for their unfortunate passion for making thin bells, of which I have already spoken at p. 349.*. The bells of the clock at King's Cross Station, of which the largest is 29 cwt., were made by Mr. Murphy of Dublin, and were bought of him from the Exhibition of 1851, as that was certainly the best large bell there. Messrs. Warner had then cast nothing above half a ton. The foreign bells in the Exhibition were very poor. Mr. Dent once had one of 8 cwt. from Paris: it was beautifully cast, but the shape was bad, and the sound very inferior to many English bells of the same weight. I think it may now be said that the art of bell-founding, which was about at the lowest point it had reached for 700 years, when the first edition of this book came out, is in

* There is a clock now making to strike on an E bell of 15 cwt. casting by Messrs. Taylor; which is less than half the weight of the E bell at Westminster, and 11 cwt. less than those of Bow Church and York Minster. A 15 cwt. bell cannot be lower than G without being the worse for it.

a fair way for revival. Possibly these few pages on the subject may do something more to help it; not so much by teaching the bell-founders their own business, as by teaching other people what to insist on from them, and how to get it.

When we began the Westminster bell business in 1855, I found there was as good as nothing of a practical kind to be learnt from books, and what little there was was contradictory, and some of it evidently wrong, and not always right even on the simple arithmetical relation of the musical notes to the different sizes of *similar* bells (using that word in its mathematical sense, of all the proportions varying alike). Probably the bell-founders have done their best to keep their secrets to themselves; and what properly belongs to them, viz. their peculiar modes of casting, I shall not interfere with; but what the public has paid for in the Westminster experiments, and what I have learnt for myself, I shall expound as clearly as I can. It will be seen too, that the alterations I have forced upon the bell-founders have been almost all in the direction of returning to the old practice, of the times when people were content to have things good, without spoiling them by trying to get grand effects out of insufficient materials. The same reaction is now taking place in organ pipes, which are made of lead and tin, and are generally too thin and too poor in tin, which is much the dearer of the two metals.

I have already said enough on the distinction between making bells in tune with each other, and making them individually good in tone. It must also be remembered that a peal of bells not quite in tune can be tuned,

although the tone or quality of a bad bell cannot be mended. They are made flatter by turning a little off the inside of the sound-bow or thickest part; and they can be sharpened a very little by cutting off the edge so as to reduce the diameter of the mouth; but this blunting of the edge is very apt to spoil the bell, and it is seldom done now.

Notes of bells. The whole theory of the designing of bells to produce the required musical notes is deduced from this mathematical law—that the number of vibrations in a second, or any other time, varies as $\frac{(\text{thickness})^2}{\text{diameter}}$; or in other words, the depth of the notes or the time of vibration varies as $\frac{\text{diameter}}{(\text{thickness})^2}$. Consequently, if you want to make (a very bad, but not very unusual thing now) a peal of bells all of the same absolute thickness (not the same proportionate thickness), their other dimensions must be as the square roots of a set of numbers in the inverse ratio of the vibrations belonging to the proposed notes. But if the thickness itself varies with the diameter, then the sizes will be simply as those numbers; and therefore all the dimensions of 'a peal of 8 tuneable bells,' according to the old phrase, which means a peal sounding the 8 notes of the diatonic scale, will be in this proportion—

$$60, \ 53\tfrac{1}{3}, \ 48, \ 45, \ 40, \ 36, \ 32, \ 30;$$

and so on for a larger number of bells, each being half the size of the octave bell below it. These are the lowest numbers which will represent the inverse ratio of the vibrations of the 8 notes without more fractions;

and they are easy to remember as a standard, from which any others may be deduced, these being the diameters in inches of a peal of bells in the key of D flat, of the best weight or thickness for such a peal, supposing that the small bells were not made thicker for their size, and therefore larger for their notes, than the large ones, as they usually are to prevent them from being overpowered when they are all rung together.

It may save some trouble to observe that in designing peals of bells we have nothing to do with what is called musical *temperament*, which was long a vexed question in organ tuning, inasmuch as a peal of bells is always played or rung in the same key. That question would arise if you took the 7th and 6th of a peal of 8 bells (counting, remember, from the smallest) to make them the 8th and 7th of a smaller peal; for in that case you see the $53\frac{1}{3}$ and 48 inches would not be in the right proportion, of 9 to 8, but the $53\frac{1}{3}$ ought to be 54; though both would be called E flat, and the error is too slight to be perceived except by very good ears. The same case occurs in playing the Westminster and Cambridge or the Doncaster quarters on the 2nd, 3rd 4th, and 7th of a peal of 8, as described at p. 191; for the sizes of those bells will be, as we saw just now, 32, 36, 40, $53\frac{1}{3}$, whereas the 36 in. ought to be only $35\frac{5}{9}$ to make it exactly in tune as the second of a peal of 6 or of 10 bells.*

* I do not profess to know these things as a musician, or to have an ear capable of judging of any such differences as those of temperament. I only know them arithmetically. There is no difficulty in finding people competent to judge whether bells are in tune, after they are made, but they have to be made by calculation and not by ear.

Weight of bells. The weights of *similar* bells, *i.e.* of those in which the thickness and all the dimensions keep the same proportion to each other, of course vary as the cubes of the diameters, or any of the other dimensions; and therefore the weights of a peal of 8 such bells would be in this proportion (making the tenor 100, for convenience of calculation)—

100, 70·23, 51·2, 42·2, 29·63, 21·6, 15·18, 12·5.

The Westminster bells, which would be the treble, second, third, sixth, and tenor of a peal of ten, are very nearly in this proportion; for in them the thickness does vary with the other dimensions, except that the smallest was made a little thicker than the others for its size, in order that its sound might be strong enough.

But we have still to ascertain what is the proper weight for any given size or note. From the practice of some of the modern bell-founders you might suppose that it may be almost any weight you please, at least within very wide limits, as one sees bells of about half the weight of old ones and yet of the same note; and then people are surprised that they sound worse.

Postponing for the present the consideration of bells to ring in peals, any one who takes the trouble to compare the weights and the cubes of the diameters in the list of the principal large bells of Europe at the end of this book, will see that the bell-founders of all ages and countries have agreed in fixing rather narrow limits for the variations of weight in proportion to the diameter of their bells. And this is by no means from any blind following of each other; for there is a good

deal of variety in the shape and the distribution of thickness over the different parts of the bell, although it all ends in this near agreement of the proportions of weight and size; which would be nearer still, but for the foreign bells (except the Russian) being taller than most of ours.

Taking 6 ft. diameter as a convenient standard to reduce them to, you will find that the *least* weight for a bell of 72 inches would be 72 cwt., which is easy to remember; or in smaller figures, 9 cwt. (= 1008 lb.) for 3 ft. diameter. And such a bell will be nearer B flat than any other note, according to the proposed universal pitch, in which A has 870 vibrations in a second, or that number multiplied or divided by some power of 2. The diameter of bells on that scale is about 13 times the thickness of the sound-bow or thickest part; for if some of them are rather thinner there, they are thicker above the sound-bow, and so the total weight is the same. But nearly all the great European bells, as you may see from comparing their sizes and weights, are very considerably heavier than that scale, and the average *modulus* for them may be taken at 4 tons for 6 ft. diameter, or 10 cwt. for 3 ft., and in that case they will be nearly a note higher. The Westminster bells are very nearly on this thicker scale, or their diameter is nearly 12 times their thickness. If they were quite so, the note of the great bell would be F, instead of a high E as it is at present, and the largest quarter bell would be C if it were quite 4 tons with its present diameter. Some of the bells in the list (if their recorded weights are right) are still heavier than this, which I shall generally

call the $\frac{d}{12}$ scale, and the other $\frac{d}{13}$; which last gives the before mentioned size of 5 ft. for a D flat bell, weighing about 42 cwt., instead of 30 or less as they are generally made now.

This $\frac{d}{13}$ scale agrees more nearly in weight than any other simple proportion with that used by the old bell-founders in the large bells of peals, which were made rather thinner than large single bells, and the small ones thicker, to prevent them from being overpowered by the large ones. The tenor of the peal at Exeter (the largest ringing peal in England, and therefore in the world) weighs only $\frac{1}{10}$th less than its weight on the $\frac{d}{13}$ scale of the Doncaster peal; and 'the great bell of Bow,' and the tenor of York Minster, and the similar one at Sherborne (lately cracked, see p. 354) are still nearer to it; although any one measuring their thickness at the sound-bow only might fancy they were on a thinner scale. The Exeter one for instance is only $\frac{d}{15}$ at the sound-bow, but the waist is 2 inches thick, or $= \frac{d}{36}$, and not $\frac{d}{45}$ as the modern founders would make it, and the weight is that of a rather thick bell. I am satisfied however that no sound-bow ought to be so thin as that proportion, and that even thickening the waist does not compensate for it. There is a fulness and softness in the sound of a thick bell which a thin one never has. The old bell-founders evidently knew what the modern ones do not choose to believe,

or more probably do not care for so long as they get paid for their bells—that it is a law of nature that a given weight of bell-metal is only capable of sounding a very narrow range of notes with good effect; and if you will infringe that law and make your bells thinner for the sake of getting deeper notes out of them, you are as certain as usual, in fighting with laws of nature, to pay for it by a more than equivalent loss in the quality of the tone.

And it happens that this loss is even greater now than it would have been a century ago. For it is a well known fact, and the experiments made for the Westminster bells confirmed it, that the copper of modern days is different from the old copper in some way that analysis does not indicate—less tough in working, capable of holding less tin without becoming too brittle, and apparently incapable of a certain softness of sound which even thin old bells sometimes have, but thin new ones never.

Before I leave this part of the subject I will give a short table which may be convenient to persons who want to know, without the trouble of calculation, of what weights and sizes the leading, *i.e.*, the largest bells of a peal ought to be, according to this scale, which ancient and now also modern experience proves to be the thinnest that you can use without sacrifice of the quality of the tone, and therefore of the pleasure which the bells are meant to give to those who listen to them. And as a peal of bells is a luxury, and not a necessary of life, it does seem to me astonishing that people will go on raising large subscriptions for them without taking the least trouble to ascertain that they get what is

really the best thing for their money, and forgetting that you pay for the same weight of metal whether the bells are thick or thin, only in one case you get them of the right notes for their weight, and in the other case of wrong, and so make the bells bad instead of good.

On account of the difference of *temperament*, which I mentioned just now, some of these numbers may want altering a little when reduced into peals of different keys, and therefore I shall generally omit the fractions of inches and cwts. For instance, the Doncaster E flat bell is 54 inches wide, although its proper size is $53\frac{1}{3}$ in. when it forms the 7th bell to a 5 ft. tenor of D flat. I shall therefore put it as 54 in the table, because a bell of that size is much more likely to be the tenor than the 7th of a peal, especially in these days of small towers; for there is hardly ever a tower built now fit to hold a good peal of 8 bells. To do that properly with a good frame, the inside of the tower ought not to be less than 4 times the diameter of the tenor bell: whereas now the bell-founders are generally required to cram peals of 8 bells into towers not wide enough to hang 6 properly. This, I may observe, has also a bad effect on the sound of the bells; but so long as the builders of towers think only of the height they can reach, of course no attention will be paid to the provisions for bells and clocks, which the makers of them are always expected to manage somehow, after the architect has done.

The sizes, weights, and notes of the new Doncaster, and the old Exeter and York Minster and Bow bells are added here, by way of introduction to what I have to

say about the proportions of the large and small bells of peals; and you must remember that neither this first table, nor the large bells of any of these 3 peals, give the best sizes or weights for single bells of those notes, or for a set of clock bells, in which the great one never has to sound till the smaller ones have done. For that purpose they ought to be from $\frac{1}{6}$ to $\frac{1}{5}$ heavier than this for any given note, *i.e.*, on the $12\frac{1}{2}$ or 12 scale, instead of 13. Thus, besides the large bells in the catalogue at the end of the book, the Queen's clock bell at Balmoral, made from the Westminster pattern, and exactly half the size, and therefore an octave above the 4th or B quarter bell, weighs $9\frac{1}{2}$ cwt. instead of 8 as in this table. There is a small bell at the new church of St. Thomas, near Portman Square, only 26 in. and $3\frac{1}{2}$ cwt., but of the Westminster pattern and thickness, which seems to me very much better than any other small bell in the neighbourhood.

SCALE OF BELLS $\frac{d}{13}$ THICK

	Diam in	Weight cwt
C	64	53
D flat	60	42
D	57	36
E flat	54	30
E	51	26
F	48	21
G flat	45	18
G	43	15
A flat	$40\frac{1}{2}$	$12\frac{1}{4}$
A	$38\frac{1}{2}$	11
B flat	36	9
B	$34\frac{1}{4}$	8
C	32	$6\frac{1}{4}$

DONCASTER CHURCH BELLS, cast in 1858

		Diam in	Weight cwt	qr	lb
8	E flat	54	30	1	0
7	F	48	21	0	24
6	G	$43\frac{1}{4}$	15	1	10
5	A flat	41	13	0	0
4	B flat	37	9	[illegible]	0
3	C	34	[illegible]	0	10
2	D	$32\frac{1}{4}$	7	0	11
1	E flat	31	6	2	5

The 4 largest of the old bells of 1722 were of the same sizes and notes, and very nearly the same weights as these, and the small ones rather heavier. The tenor of Mr Mears's peal, cast in 1835, and burnt in 1853, was rather heavier, but thinner, a note lower,

Exeter Cathedral Bells, mostly cast in 1676.							Bow Church, 1762, and old York Minster, 1765.					
Weight			Diam.					Diam.		Weight.		
cwt.	qr	lb.	ft	in.				ft.	in	cwt	qr	lb
67	1	20	5	11½	B flat.	10	C . .	5	4½	53	0	[illegible]5
46	3	14	5	4½	C	9*	D . .	4	9½	34	2	6
38	1	16	4	11	D	8	E . .	4	[illegible]	26	0	13
30	1	12	4	7	F flat.	7	F . .	4	[illegible]	21	0	23
21	0	[illegible]	4	1	F	6	G . .	3	8	16	0	4
15		0	3	10	G	5	A . .	3	5	13	2	22
12	2	0	3	4½	A	4	B . .	3	2½	12	0	7
10	1	[illegible]	3	1½	B flat.	3	C . .	3	0	10	0	0
9	3	20	3	0	C	2	D . .	2	10	9	1	5
[illegible]	3	[illegible]	2	9½	D	1	E . .	2	8½	8	3	7

I was told that if the large bells at Doncaster, and at St. Nicholas's, Aberdeen, (which is cast from the pattern of the 3rd bell at Westminster, but a little thinner and therefore E flat) were made so heavy in proportion to the small ones, the trebles would be overpowered and not heard. The fact is that they sound rather unusually distinct and clear. And you observe that the tenors of these three of the largest old peals in England are actually heavier in proportion to the octave bells above them, than the Doncaster tenor is. In short, that excuse for making the large bells thin out of consideration for the small ones is proved to be un-

* For some reason, which I do not understand or believe in, the founders seem to have a habit of making the last but one bell of a peal disproportionately thin, as you see it is in both these peals. I had often observed that it was apt to be the worst in the peal. Rather different weights are given for some of the York and Bow bells, but not to any material amount. The present York Minster bells are made from the old patterns: I have never heard them rung, but some persons who have think them inferior to the Doncaster peal, though so much heavier. The bells of St. Saviour's, Southwark, are of about the same weight as the Bow bells, but rather flatter, and they are not thought so good. The Exeter bells are rather flatter for their nominal notes than the others in this list.

founded. This Doncaster peal too has proved another thing, when compared with the deeper one of 1835, viz. that a 30 cwt. bell 4 ft. 6 in. wide and thick enough to be E flat does not sound weaker but stronger than a bell of the same weight expanded and attenuated into 4 ft. 10 in. and so brought down to D flat. Of course this partly depends on its being properly clappered, which very few bells are. People seem not to know that too light a clapper brings out a sound inferior in quality as well as quantity to a proper one.

I do not say that the large bells of a ringing peal ought to be on as thick a scale as the small ones; though in a set of clock bells there need be no difference, because the small or quarter bells have always done before the great one begins to sound. But I do say that the difference is generally made much too great, and the large bells of nearly all modern peals are spoilt by being made of too low notes for their weight, or too light for their note. The 3 or 4 largest bells should be on the $\frac{d}{13}$ scale and no thinner, and the smaller ones may gradually increase in thickness up to $\frac{d}{12}$ in a peal of 6; to $\frac{d}{11}$ in a peal of 8, as the Doncaster treble is; and perhaps to $\frac{d}{10}$ in a peal of 10 or 12 bells: beyond that thickness a bell becomes too much of a lump of metal to sound freely.

A peal of 12 bells appears to me to be a mistake, as it is almost impossible to ring them distinctly; and as a matter of fact it is very seldom that all the bells even

of a peal of 10 are rung, and still more seldom that they are rung well. There seem to be very few sets of ringers in London now capable of ringing true changes: at least I constantly hear false ones, with the same change repeated many times over. I think even 8 bells too many unless the tenor is at least 18 cwt., and that not E flat but F sharp, remember. There is many a peal of 8, perhaps the great majority that have been cast in the last 20 years, which would have sounded better if the same or even a less weight of metal had been spent upon 6 good bells a note or two higher. I know one especially where you can scarcely hear the tenor because it is too thin and the treble because it is too thick, and where the ringers have hardly room to stand, and the ropes cannot fall straight, and the walls are cut into, and pieces of the frame left out, to make room for the bells to swing, all because a certain number of people were determined to have 8 bells at all hazards, which are practically worse than 6 now that they have got them. The tenor of a peal of 6 should not be less than 12 cwt., and that not lower than G sharp.

Shape of bells. Hitherto I have assumed that the bells are to be of the well known and universal shape of church bells, as shown accurately enough for this purpose at page 198. And I am convinced it is the right shape, notwithstanding the multitude of public and private assurances which we had that it is wrong, and that the hemispherical form, or something like it, is right. The persons who kept making these suggestions evidently did not know that large and small bells require different shapes. Why it is so, I do not pretend

to explain. But the hemispherical form had been used for ages in small clock and house bells up to the largest size at which it can properly be used. I had tried myself for several years, and with several founders, to get one made as large as 9 inches diameter that would sound well in a house clock, and I was obliged to give it up and be content with one of 7 inches, which seems to be the limit of their musical capacity. There was a very large one in the 1851 Exhibition, but it was obliged to be struck with a muffled hammer: otherwise the sound would have condemned it at once.

I know that bells of 3 or 4 cwt. of that shape are made for cemeteries, for which their horribly doleful sound is appropriate enough; and as they have the advantage of not being heard nearly so far as bells of the common shape, it is perhaps still more appropriate. But those are not the qualities usually sought for in either ringing bells or clock bells.

On the other hand, small bells of the usual church form, such as musical hand bells, require to be thinner and straighter in the side, or more conical than larger ones, which are bad if the sides are less hollow than in fig. 33. I exhibited an exact 6 in. bell-metal model of the Westminster bells at the Royal Institution in 1857, and it sounded worse than a common door bell, or a railway hand bell. But above 2 feet in diameter, or perhaps less, all these peculiarities vanish; and according to my observation and experience, and the universal practice of the bellfounders of all ages, the long established shape and proportion of church bells appears to be equally right for a bell of 4 cwt. and of 220 tons, the probable weight of the largest Russian bell. I may

just mention here that the form of a very prolate hemispheroid, which the Chinese and Indian bells have, is so manifestly bad, that no one need hear them twice to know that that form at any rate is wrong.

But when you have to design bells for construction it is necessary to go somewhat farther than this general conclusion; inasmuch as what we may fairly enough call the established form of bells, when speaking popularly, or comparing it with a very different form, will be found to have considerable variations of its own--considerable at least to the eye of a person who knows what a great difference in tone may be produced by an apparently small difference in shape. This, and the best proportions for the composition of the metal, were the two great points to be settled in the experiments and observations, which, as I have already said, were made before and during the two years which were occupied in casting the Westminster bells. It would be tedious and useless to describe the different variations that were tried. They ended in our coming to the conclusion that the best shape was something between the most common English pattern and the usual foreign one. It is indeed a good deal nearer to the English than to the continental pattern, except the Russian, which I was surprised to find from a section given in *Lyall's Russia*, after the first Westminster bell was made, agrees very nearly with that pattern.

After trying and observing the effect of a great many patterns, and without any *à priori* theory in favour of any particular curve, I saw that the one which we all thought the best in effect was very like an ellipse in section, though not the same ellipse as had been

previously, and is still used by some of the English founders; and on trying it I found that the shape for the inside section, which we had thus gradually arrived at empirically, was actually a very close approximation to the quadrant of an ellipse of which the major axis is $\frac{13}{24}$ of the diameter of the bell, and the minor $\frac{6}{24}$, or $\frac{1}{4}$ of the width of the mouth, or $\frac{1}{2}$ the inside width of the bell near the top. These 13 *parts* (as it is convenient to call the 24ths of the diameter) are however not enough to complete the height of the bell, and the rest of it is simply a cylindrical continuation, as usual before. In large bells of this pattern the inside of the top is 16½ parts above the bottom of the bell, and the top itself may be described with that radius from the middle of the bottom: in smaller ones it is found expedient to make the height 18 parts, or $\frac{3}{4}$ of the diameter, and rather more arched than in large ones.

The rules for describing the outside are not so simple; and it is hardly worth while to go into them, as they are purely empirical and only designed to produce the following results:—The sound-bow or thickest part ought to fall at 2¼ parts from the lip, measured along the inside curve. At 7 parts from the lip, the bell ought to be at least as thick as half the sound-bow, but never thinner than $\frac{d}{26}$, even if the sound-bow is thinner than $\frac{d}{13}$, which I think it never should be. From that the thickness gradually decreases to $\frac{\text{sound bow}}{3}$ at the top; but that again seems never to have been less

than $\frac{d}{39}$ in the best old bells, even in those with a sound-bow as thin as $\frac{d}{15}$. From the sound-bow to the lip outside, the suitable curve may easily be drawn by hand, or by some empirical circle-radius which you may find convenient.

This construction makes the sound-bow rather fuller outside than has been usual. According to all the sections in books, and most of the bells that I have seen, you can lay a straight edge against the lip and the top shoulder of the bell; but in the Westminster pattern the straight edge would be thrown out a little beyond the lip, by the protuberance of the sound-bow. I do not profess to give any reason why this pattern should be any better than the more hollow ellipse, of major axis 12, which is the more usual English pattern,* instead of 13, or than the foreign pattern, which is not an ellipse at all but a very much *less* hollow curve, and not ending horizontally at the mouth: all I can say is, that having tried them all, both I and other people who examined them came to the conclusion that this is the best in effect. The greater tallness of the foreign bells, which has sometimes been copied in English ones, has long appeared to me to be a pure waste of metal as regards sound, if not worse; besides being a serious incumbrance in the increased momentum and centri-

* So far from a neat proportion of that kind having a presumption in its favour, I think the presumption is against it; for we may be almost sure it was adopted at a guess, *because* it was a neat proportion, and not from induction founded on experiments, as the Westminster or Doncaster pattern was.

fugal force of the bell in ringing; and I believe all the English founders are of that opinion now.

Composition of bell metal. Without going over the various experiments with different metals, both simple ones, such as steel or aluminium (the worst of all), and compound ones of various alloys, which I described and exhibited in a lecture at the Royal Institution in 1857, it is enough to say here that not one of them was equal or nearly equal in the quality of the sound to that alloy of copper and tin commonly called bell metal, for which various proportions are given in the books from $\frac{1 \text{ tin}}{3 \text{ copper}}$ down to $\frac{1}{4}$: I say *down,* because the more tin there is the 'higher' the metal is called. I have said before that 3 of modern copper to 1 of tin may be taken as the turning point between brittleness and toughness; and it is the proportion which gives the greatest density or specific gravity of the alloy, in very good casting as much as 8·9, or equal to that of not merely cast but rolled copper, though that of the tin in the alloy is only 7. No specific gravity less than 8·8 ought to be allowed. Although part of Mr. Mears's Westminster bell is only 8·32, another part is 8·8. The lightest piece of the former bell that was analysed was 8·847, according to Dr. Percy's report, and a bit near the bottom was 8·94.

It is clear that the old bell-founders aimed at something near this proportion of 3 to 1, and sometimes exceeded it a little in the quantity of tin, or tin and antimony together, which excess their copper would bear though ours will not. I have already given the reasons why $\frac{22}{7}$ was fixed on for the Westminster bells, and

there is no doubt that that composition is strong enough, provided it is soundly cast and has been twice melted. But for all that I propose now to vary it a little, for a reason having no relation to the toughness, but for a chemical reason of a different kind. It happens, oddly enough, that neither this, nor any one of the proportions given in books or commonly used for bell metal, agrees with what are called the chemical equivalents or atomic weights of the two metals, which are—copper 32, tin 59: 3 to 1 does not, which some of the books call 'an excellent metal for large bells;' nor 3½ to 1, which others recommend and Messrs. Warner now use; nor 4 to 1, which is the common soft metal of house bells, and sometimes wrongly used for church bells; nor does $\frac{22}{7}$ quite; but $\frac{13}{4}$ does: for $\frac{13}{4}\ 59 = 192$, which is a multiple of 32. In other words, such bell metal would be a true chemical combination of 6 atoms of copper to 1 of tin ($Cu_6\ Sn$), though it is only 3¼ pounds or ounces of copper to one of tin.

Lord Rosse made his great speculum on this principle, of 4 atoms of copper to 1 of tin ($Cu_4\ Sn$), or in the proportion of 128 to 59 by weight; and it is said that a very slight deviation from it runs great risk of spoiling a speculum. I am told by persons who have made experiments both in that and other alloys, and some instances of it are given in books, that the combinations which are definite multiples of the atomic weights are less liable than others to separate or become unhomogeneous in casting, like Mr. Mears's bell, and that they are better in other respects: certainly the difference between the appearance of the fracture of the atomic speculum metal and of other metal very slightly

deviating from it, is remarkable. I was very near prescribing the above mentioned atomic proportion for the Westminster metal, and indeed I published it as a suggestion in 1856; but I was then assured by persons who knew more of casting than I did, that the atomic principle was of no consequence in the metallic alloys. But although not one bell in 1000 may fail in this way, to the extent that Mr. Mears's bell has, and small ones probably not at all, because they cool before the metals have time to separate, it is clear that there is a tendency to do it; and indeed I find it is well known at Woolwich as a thing to be provided against in casting large guns of gun-metal.

It seems to me at any rate imprudent not to avail ourselves of this undoubted law of nature, especially as there is an atomic combination which happens to be a particularly convenient proportion, being exactly a mean between the 3 to 1 which is just too brittle to be safe, and the $3\frac{1}{2}$ to 1 which the bell-founders like because it is easier to tune, but which is certainly softer and less sonorous than it need be. I should now therefore require large bells to be made of this $\frac{76{\cdot}5 \text{ copper}}{23{\cdot}5 \text{ tin}}$, or Cu_6Sn; and they should then be rejected as unhomogeneous if any part of the bell is proved to be beyond the limits of either 77 per cent. of copper or 23 of tin. It must not be supposed however, that this would have prevented the porosity of Mr. Mears's bell, which is a quite independent defect, and would have made the bell a bad one, even if it had not also miscarried in composition and so fortunately destroyed itself.

The only other atomic combination within the range of bell metal is $Cu_7 Sn$, or 19 copper to 5 tin by weight; but that is too soft, except for small house bells, which are thinner and have clappers much larger in proportion than church bells. Old Tom of Lincoln and the old York Minster bells of 1765, and probably the Bow bells, of nearly the same date and made from the same patterns, contained ·03 of antimony, which has a hardening effect like tin. That is much too large a quantity to have got in by accident; but I am not prepared to give a positive opinion whether there is any advantage in it or not, because the few experiments which have been made were not conclusive by themselves. There was no perceptible improvement in the sound from introducing about ·03 of antimony into a small bell, and the experiment that was made as to strength was not a fair one, because the same quantity of copper was not taken. The antimony diminishes the specific gravity of the alloy, which tin does not, though so much lighter than copper by itself. So far as I have an opinion on the point, it is at present against the antimony, and the bell-founders have the same opinion. Very small quantities of iron, lead, zinc, arsenic, and sulphur sometimes appear in the analysis of bells; but they are mere impurities. I have indeed seen lead and zinc in considerable quantities innocently put down in books as ingredients of bell metal; but it has been merely adulterated; for both those metals are injurious and have no business there at all, especially the lead: a little zinc is sometimes put into small bells, I do not know for what reason.

Steel bells. I have frequently been asked my

opinion of these bells, which are now made both in Germany and at Sheffield. I have not myself heard any but quite small ones, and those were very inferior indeed to bell metal; and I never received but one opinion as to the inferiority of the large ones also, from good judges who have heard them. I told the makers, who wrote to me on the subject, that if they meant to convince the public of their value, they ought to exhibit a large cast steel bell together with a good bell metal one of the same weight. They are however much cheaper than bell metal, and that would be a good reason for having them, if large bells were a necessary of life, and if it was impossible to find the money to pay for the proper materials for making them. I understand they require hammers two or three times as heavy as bell metal bells: if so, there would be little saved in using them for large clock bells, as the clocks would cost much more.

Silver. The most inveterate of all popular delusions about bells is the notion that old bells had silver in them, and that all bells would be improved by it. There is not the slightest foundation for that belief. Nevertheless we had some experiments made for the purpose of being quite sure that silver was of no use, either with reference to sound or strength of the metal; several different proportions were tried, beginning with sixpence in a bell of nearly a pound weight, and it was clear that the silver rather did harm than good in both respects. I suppose the delusion has arisen from the ring of shillings and half-crowns, which justifies no such inference any more than in the case of aluminium, which some people fancied would make very fine bells,

until I exhibited one at the Royal Institution, which M. St. Claire Deville of Paris was good enough to cast for the purpose; and the sound was worse than of cast iron. A bell of copper and aluminium was also bad, though the bronze of 9 copper to 1 aluminium is in other respects a very superior metal to either brass or any alloy of copper and tin (see p. 95). No composition for bells has yet been discovered equal to copper and tin in the proportions I have given. There was a large bell of iron and tin in the 1851 Exhibition; but that also was very inferior indeed to bell-metal; and it required an enormous blow to bring out the sound, and was at last cracked thereby.

Moulding. There are two different ways of making the moulds for bells. As to the internal mould or *core* they are nearly identical, that being made by covering a cone either of brickwork or of cast iron with moulding clay, which is *swept* over into the shape of the inside of the bell by a piece of wood called a *sweep* or *crook* fixed to an axis or spindle set up in the middle of the core. The advantage of the iron core is that it can be lifted up and put into a furnace to dry, instead of lighting a fire inside it. At this point the difference between the two methods begins. The old method is to make a clay bell on the core by means of another crook, and when that is dry to make the outside mould or *cope* on the top of that. The cope has hair and hay-bands, and in large ones, iron bands worked into it, to make it hold together and lift off when it is dry; then the clay bell or *thickness* is knocked to pieces, the cope dropped down again and weighted with earth in the pit where the bells are cast, and the metal poured

in at the top through one hole, another being left for the air to come out at.

In the other way there is no *thickness* made, but the cope is an iron case lined with clay and swept out by an internal sweep to the shape of the outside of the bell. The *wires* or ornamental rings round the bell are made in both cases by the second sweep, and the letters and any other ornaments are pressed by stamps into the clay of the cope while it is soft. These iron copes can be bolted down to a plate under the core, and therefore do not require to be sunk so deep in the ground, provided only proper care is taken to get a high enough head of melted metal above the bell, or else it is certain to be of bad specific gravity and probably porous in a casting of any considerable size, as in the top of the first Westminster bell, where the metal ran short. This second mode of casting is used by Messrs. Warner, and the other by Mr. Mears, and I believe other bell-founders. Small bells, up to about 1 cwt. are generally cast in sand, like iron, from complete models which are kept, and not in loam moulds made by sweeps. Bells are always cast mouth downwards, so that the sound-bow, which is by far the most important part, may have the best chance of being sound by having the greatest pressure of metal on it. The importance of this was illustrated by Lord Rosse's experiments with large cast iron crucibles for melting speculum metal in, which were always porous in the bottom, which is their most important part, until he had them cast with their mouths upwards.

Bell-metal melts at a temperature far below that of the copper, as is usual with the alloys of one easy-

melting metal. Small bits will melt in a common house fire. It is melted in a reverberatory furnace, in which the fire is at one end of a long shallow trough which holds the metal, and the flame is drawn over it to reach the chimney at the other end and is reverberated down upon it from a 'bridge' and a low roof over the trough. The different founders use different fuel as well as different ways of moulding. Mr. Mears, as his counsel told us, still uses wood; and I suppose the old founders did, unless they used charcoal, as I understand they do in Russia, which is probably far better, because wood contains so much moisture that it takes much longer to get the requisite heat up with it, and it is notoriously a bad thing to keep the metal long melted getting up the heat. At Woolwich they have given up using wood for that reason, and use coal or coke in melting gun-metal, which is bell-metal with much less tin in it. Messrs. Warner also use coal. In order to test this as far as possible, I gave to them and Mr. Mears the same pattern for a bell of about 12 cwt. for the two new churches at Doncaster; and the result, in the opinion of everybody there, is very decidedly in favour of the coal-cast bell; but whether from that cause or some other difference in the general management of the casting, of course I cannot say. Most of the metal of Mr. Mears's Westminster bell was nine times as long in the furnace as Messrs. Warner's (which, however I suspect was run too soon), and was also four times as long running into the mould, though there were 2 tons less of it. I have no doubt that that slow running contributed to its unsoundness. Lord Rosse specially mentions the importance of quick run-

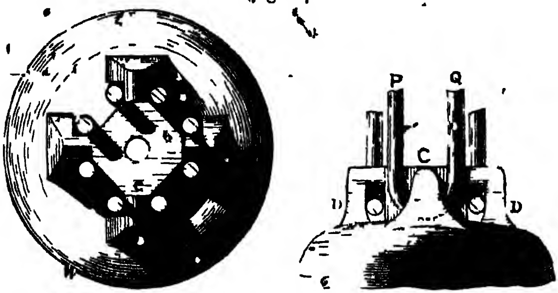
ning of large speculums, which again are bell-metal with a higher quantity of tin.

Mending cracked bells. Whenever a bell of any importance cracks, there invariably follows a flood of suggestions, public and private, for mending it: generally by 'cutting out the crack' in some way or other. And as there exists in some persons what is called colour-blindness by the world at large, so there are persons to whom a bell so divided—and others apparently to whom a bell with six cracks in it, sounds (at least they say it does) no worse than when it was whole, though to other people's ears the tone is generally altered several notes, or is made otherwise intolerably bad. Another way of mending, which is continually being reinvented, is by what is called burning the parts together; *i.e.*, cutting the crack wide enough to let hot metal be poured in and through, which is done until the constant application of it partially melts the faces of the division and then the running is stopped and left to cool. This may *perhaps* answer in very thin bells, though the cracking of one of Sir C. Barry's gun-metal hands which were put together in that way is not very encouraging even for much thinner castings; and the contraction and consequent tension of the metal, would most likely crack the bell again as soon as it is rung. There is no evidence that I can learn, of any bell as large as a common church bell having been successfully treated in this way yet. And if the bell has cracked from any radical defect, as both the Westminster bells have, of course it is absurd to think of mending it, even if it were otherwise possible; for the same defect would make it crack again.

BELL HANGING.

New bell crown. I said at page 353 that I should describe a new kind of bell crown (using the word in its proper sense, of what is put upon the head, and not of the head itself as the bell-founders do) which has a good deal of the same advantage as the mushroom

Fig. 64.



crown and avoids the expensiveness of the iron work which that involves. First suppose a lump of metal as broad as the bell-stock is to be, or about $\frac{1}{6}$ of the diameter of the bell, cast on the top, with a round hole through it, for the clapper bolt, which fits square into the stock, as in the mushroom. From this lump there project 4, not 6, *canons* C, much thicker than usual, of a section like an ∩ with a slice of the top cut off; and these are again joined to the top of the bell by strong lumps of metal D. The section of the canons has been drawn quite round in this figure by mistake: otherwise it is a plan and side view of the top of such a bell with portions of the bolts P Q, which are mere loops of round iron with nuts above the stock. By placing the same bolts in two different ways, each with one leg in the

stock, or two of them inside, and the other two outside of the stock, you may get 4 different pairs of places for the clapper to strike, with the same stock and without any cutting of it, and the stock itself is far less cut into and weakened than by the usual canons which are necessarily much taller. The Doncaster bells were the first peal made in this way.

On the old plan too, the clapper bolt is always cast into the bell, and must be cut off and a new one stuck on in some way, to turn the bell at all, which is an awkward job, and postpones the turning of bells for years after it ought to be done. And in connexion with that it is another advantage of this plan, that it enables the clapper bolt to be adjusted both for length and position, which cannot be done when they are cast in. The length of that bolt ought to be more or less according as the bell is hung more or less high in the stock, in order to bring the point of suspension of the clapper below the gudgeons or pivots of the bell, without which it will not swing or strike properly; and again, if the bolt is cast in a little on one side, the clapper will not strike true and the time between the blows will be unequal, which makes it impossible to ring the bells truly. If some such plan as this had existed in old times, whereby a bell could easily be turned in the stock, many a fine old bell would now be alive which got cracked from being constantly struck in one place, and so worn too thin. These four short and thick canons are moreover much stronger and less liable to crack than the usual six thinner and longer ones.

Opinions differ whether large bells should be what is called 'tucked up in the stock,' or the top of the bell

made higher than the 'pivots or gudgeons.' The advantage of it evidently is that it diminishes the centrifugal force, or sideway strain of the bell on the frame; and if friction were out of the way it would of course make the bell easier to raise and ring. A few years ago there was a small controversy on the subject, in which Mr. Baker, who is mentioned at p. 352, and some of his friends expended some elaborate mathematics in proving this very self-evident proposition, which they supposed to have been denied. But friction is *not* out of the question; and as a bell in swing is in effect a pendulum, and not (as I have even heard bell-founders represent it) a body lifted by a steady pull like a lever, it may very easily happen that a certain amount of friction on the pivots may make it impossible to make the bell pendulum swing through 360° by any practicable force that can be applied to it at the beginning of its motion, which is the only time when the rope acts upon it. Mr. Taylor said at the time I have referred to, that a bell of about 52 cwt. at Hereford which he and some other boys used to raise and set (*i.e.* ring till it stands mouth upwards) was made unraisable by them by being rehung and at the same time 'tucked up;' and so confident was he of the mistake of this mode of hanging, that he offered to fill Mr. Mears's great bell at York with beer if *any number* of men could set it, and they never could, as *Browne's History of York Minster* also testifies, though Mr. Mears contradicted it in the *Builder* when Mr. Taylor stated it. I know another person who was present when 30 men tried in vain to do it.

The great foreign bells are all hung quite clear of the stock, I understand; and nobody has ever denied

that when so hung the clapper strikes much better; indeed when they are hung high the clapper always 'rises false,' or hangs on the low side of the bell instead of flying after it and striking the high side; and this also tends to make the bell more difficult to raise. There is moreover a remarkable difference in the facility of tolling, according as the bell is hung low or short. I can toll the two largest bells of Doncaster church together, weighing 2½ tons, one with each hand, whereas it is difficult to make a high-hung bell toll at all. I am surprised that very large bells, say above 2 tons, are not hung on long friction rollers—*i.e.* so much of the circumference of a friction wheel as = the circumference of the gudgeon or pivot of the bell. I recommended it for the great Leeds bell, the only one of that weight in England that can be safely rung at all, but the Town Council or their architect knew better. I have no doubt if that had been done, one or two men could have raised the bell, and it might have been rung, say at 9 o'clock every evening, like the smaller but fine bell of St. Mary's Cambridge, and other bells elsewhere. Of course brasses must be put to keep the gudgeons in their place against the side swing. And by the way, let me say a word here to warn those whom it may concern, that if the smaller bells of a peal jump out of their brasses when they are new, it is because the gudgeons are not sunk deep enough. I have known that happen several times. Of course the founders always denied that that was the reason, but as I cured it myself at Doncaster by getting deeper brasses, the denial was not worth much.

Bell towers. If the great tower at Westminster had

been the bell and clock tower, as it ought to have been, the tower itself would have had some use and meaning, instead of being apparently built for nothing but to carry that abominable flag-staff and the iron box roof which it is stuck into; and the bells might have been rung occasionally, the 5 clock-bells with 5 others forming a complete peal such as there is not in the world. There is no room for such a peal in the present clock tower; and if you tried to swing those bells at the height of 200 feet in such a tower as that 'grandfather of clock cases' (as somebody called it), it would probably soon make an end of both tower and bells together, though Sir C. Barry once told me he thought it might be done. The great foreign bells, such as Erfurt and Paris, which are nearly as heavy as this, are rung occassionally; and anybody who has tried the experiment, or ever attended to the sound of bells, knows that they sound much better swinging. There is very good foundation for the popular association of ringing with joyfulness and tolling with dolefulness. To be sure, some of our legislators (including the Prime Minister who talks of the 'gloominess' of that style of building which has the largest windows in the world) were astonished that a 13½ ton bell striking the long hours should sound monotonous, and rather doleful than cheerful. But the laws of nature will not alter even for the British House of Commons, and large bells with slow and long vibrations must be struck slowly, and a repetition of heavy blows by machinery is apt to be monotonous, and monotonousness is seldom cheerful—except, I suppose, in what is called classical architecture; of which monotonous repetition is as characteristic as variety is of Gothic.

Perhaps the present Commissioner of Her Majesty's Buildings, Bells, and Clocks is not only to put down everything Gothic, and to cure cracked bells, but to teach us how to make large clocks strike cheerfully.*

I know it has been said that swinging even 5 or 10 tons of bells to make their clappers strike them is a very unscientific and barbarous proceeding. I remember a gentleman taking some pains at the Architects' Institute to show that bells sounded just as well still as swinging, and he perfectly succeeded with his experiments in convincing the audience that they did not. Another reason for swinging the bells in a peal is that it would be difficult to keep time otherwise; for the large bells acting as pendulums swinging a large arc regulate the time of the whole in a way that nothing else could. In chiming or tolling the bells, *i.e.* swinging them a very little way, only just enough to meet the clapper, they act still more distinctly as pendulums, and the small bells are swung further than the large to make them keep the same time. Sometimes peals of bells are rung now by merely pulling the clappers, as at St. Albans, and Merton Chapel, Oxford, and Chester Cathedral, and perhaps other places where they have destroyed the belfries in order to open the tower a story higher. No one can hear that style of ringing without perceiving its miserable effect compared with even chiming, and much more with full ringing.

* It is worth observing, that all those complaints about the doleful sound of the clock striking were before the quarter chimes were heard. Some people, who did not like the great bell alone, were quite reconciled to it by the quarters, and were very sorry when the Board of Works stopped them. Probably also, a better bell than we now know that to be would sound less doleful than either it or its predecessor, which was unsound too.

In some other places this way of ringing even a single bell has been adopted from pure laziness.

A large bell may be tolled easily by one man, if it is properly hung, though not if it is 'tucked up in the stock,' and so there is no excuse for 'clappering,' which sometimes cracks bells besides. I should hang a very large bell for tolling only, on wedge shaped gudgeons, so as to move with very little friction, and put a stop to prevent it from being pulled too far. Where the tower is too weak or too small to allow the bells to swing, or where you cannot get a belfry high enough for the rise of the ropes (which requires 18 feet at least to be safe), the proper way is to put levers and not wheels to the stocks, hang the bells low in the stock so as to toll easily, put much heavier clappers than would be used for ringing in full swing, and let the bells be only chimed. Few people know how good the effect of this is, first because it is seldom done at all, and secondly because there is hardly a bell in England which has a clapper heavy enough for tolling; the only one I know is at the Doncaster Cemetery, where I had the bell hung in this way, and a clapper of exactly twice the bell-founder's weight put in. It is full $\frac{1}{30}$ of the weight of the bell, which has been tolled for at least half an hour a day on the average for 5 years now; and this is another proof of the folly of pretending that a clock hammer only $\frac{1}{10}$ of the weight of the Westminster bell would have cracked it if it had been ever sound. Whenever the peal at All Saints Church in Margaret Street is completed, I should treat it in that way, except a few of the small bells, which may be hung to ring. These bells are gradually being made

as a copy of the Doncaster peal, but the area of the Doncaster tower is nearly three times as great, and the walls far stronger. I am sure therefore that a peal of $5\frac{1}{2}$ tons will not be rung often in that tower, and if they are not chimed they will be clappered and spoilt; which will be an ignominious end for the best—I may say, the only good modern peal in London; for the larger bells of all the rest are too thin, and many of them bad in other ways besides. I can hear that the tenor is already clappered; and from that and the smallness of the tower, it sounds very inferior to its elder brother at Doncaster. The clapper is too light also, as usual.

The clappers in English bells are generally hung by an iron strap to a D-shaped loop at the end of the clapper-bolt with a piece of leather between. This is all very well while the leather lasts, but it does not last long, and people generally neglect to renew it, and then the iron strap works on the iron bolt, often without even any oil, and they both wear out, and the clapper becomes practically longer and strikes the bell too near the lip and cracks it. Where there is room for it, as there always may be in large bells, it is much better to fix the clapper in a wooden block, cut in two to admit both the bolt and the clapper, the two halves being strapped and screwed together after it is put in. The wood should not be oak, or it will rust the iron: elm or ash will do very well. All the bolts of a clapper should have holes in and wires through them, to keep the nuts from shaking off, which may let the clapper fly out and very likely break the bell.

I have spoken incidentally of the weight of clappers

already. English clappers are generally very much smaller than what is given as the foreign proportion, viz., $\frac{1}{44}$ of the weight of the bell, and they are generally too light even for our thin bells. From this cause you can hardly hear the large bells of many peals distinctly; and the striking of clocks is generally feeble, from the smallness of the hammers. There is no doubt, too, that bells sound ill as well as weak if their clappers are too light. That same Doncaster cemetery bell was in the 1851 Exhibition and remained at Messrs. Warner's unsold for some years afterwards, till it occurred to me that the clapper was too small, as the bell was very thick for a modern one, being cast from an old pattern. I advised them to try a clapper twice as heavy, and then I found the bell was a very good one, and it sounds unusually well for its size, chiefly on account of its thickness and the heavy clapper. The reason why too light a clapper not only makes a bell sound weaker than it ought, but worse, no doubt is that it does not thoroughly rouse the whole mass into vibration.

I know two churches where the bells are hung in cast-iron stocks, which can be made perhaps lighter than wooden ones; and they avoid the shrinking and swelling to which wooden stocks are liable, especially if they are not painted. The bells hung in that way certainly ring remarkably well, and require less attention. But perhaps there is some risk of the stocks cracking, and they would be more expensive generally. So I am not prepared to give a decided opinion either for or against them on the whole.

Bell-frames are rather beyond the scope of this

book, and I have spoken of them in the book on Church-building. The great point is to make the frame strong enough not to change its form under the swing of the bells. At the same time the elasticity of the wood is useful in taking the force of the swing off the tower, as the springs take the shake off a carriage; and for that reason the timbers of the frame itself should never touch the walls; at any rate not the upper beams. For some reason or other the bell-founders' men will never make the bed for the *slider* under the bell as a circular arc, struck with a string from the gudgeon as the centre, unless they are made to do so. It must be obvious to everybody who knows what a circle is, that the sliders must slide under the action of the *stay* of the bell (I need not explain these terms to anybody who is likely to attend to this) with much less friction in a circular arc than on a straight edge. I made this alteration 26 years ago in the first peal of bells I ever rang, and I lately got it done, rather unwillingly, at Doncaster; but besides those instances I never saw it anywhere. Sliders are generally made much thicker than they need be. Boards should be put over them to prevent the grease from dropping onto them, as wood runs better on wood without it. If it wants anything to diminish the friction, black lead is the thing. A mixture of oil and grease is best for the gudgeons, and a little brimstone flour has a curious effect in aiding the operation of the grease. I need hardly say that many a pound may be saved by a few shillings spent at the proper time in keeping all the iron-work of bells in order, properly screwed up, free from rust, and the wood-work painted

also: only oak should not be painted for a year after it is put up.

Few persons, and fewer architects, appear to know how much the sound of bells is muffled and lost by boxing them up in small bell-chambers, putting them below the windows, making the windows themselves too small; and filling them up with close louvres. I have said a little about this also in the *Lectures on Church-building*, but it is equally appropriate here, and I can now enforce it by examples. The architect of the Leeds Town-hall built the bell-floor so much below the sills of the windows, and so much of the sound of the great clock-bell was lost thereby, that they had to raise the floor several feet and rehang the bell; and this after the very same thing had happened at a church close by only a few years before. The louvres or rain-blinds of the windows are still twice as close or numerous there as they need be, and of course tend to obstruct the sound. It is strange that architects cannot remember that the bottom edge of one louvre-board need never be as low as the top of the one below it, as rain does not usually go horizontally, and no louvres will keep out snow, and it is of no consequence if a little rain and snow do come in, as the wood and iron-work should be always kept painted, and wet does the bells no harm. It is a good plan to cover the bell-chamber floor with zinc, laid so as to send off any water into a spout.

The great clock bell of Canterbury cathedral stands on the top of the great tower. It is considered a good bell, and is on the old scale of thickness, being above twice the weight of the Exchange clock bell of the

same note; but when I heard it it obviously had a very insufficient hammer. It is the practice in Suffolk, and perhaps elsewhere, to have small clock-bells of only 2 or 3 cwt. hung in an open frame outside the top of the tower, and they are heard farther than many bells of ten times the weight inside a bell-chamber and below the windows, especially as the clock-hammers of large bells are seldom heavy enough. The 30 cwt. clock-bell of Doncaster Church, which has eight large windows down to the bell-chamber floor, and no louvres, is said to have been heard 11 miles by night and 7 by day; of course with the wind in its favour. For it is a remarkable fact, by no means yet explained, that a wind hardly strong enough to move a leaf allows sound to be heard three or four times farther in the direction of the wind than against it, although the velocity of sound is enormously greater than of wind in the most violent storm.

The well known story of St. Paul's clock being heard at Windsor, striking 13, by a sentinel who was charged with being asleep, is often regarded as fabulous, and may well appear so now that one can seldom hear it two miles off. But Reid says in his book on clocks that he heard it there himself, and I have heard an officer who was quartered there say the same. I suspect the reason why it sounds so feeble now is that the clock has been neglected or mismanaged, so that instead of lifting the hammer 10 in., as it used to do, it does not rise perhaps 3 in., as that is by no means a rare occurrence in church clocks.

Whether there are louvres or not, the windows of a bell-chamber should always be completely covered

with strong wire netting to keep out birds, at least where there is woodwork, though they seem to have no fancy for the cold iron roof and beams at Westminster. As I have seldom had to praise the architectural arrangements there, I am glad to be able to say at last that I believe that is the best bell-chamber in England. The height of the bells above the ground (201 feet) is valuable, both in spreading the sound far, and preventing it from being too loud close by; and the place could hardly be more open than it is: you can not judge from below how large the openings are, but you may see the great bell from the South Western Railway and from some places in St. James's Park; for there are no louvres; and the floor is at last flagged so as to throw the rain off, though it was at first cleverly laid so that the water stood in a pond. Whenever the clock is allowed again to have a bell to strike the hours on, people hearing it at long distances must remember that at 6 miles it will sound nearly half a minute too slow, and so on in proportion, at the rate of 4½ seconds to a mile. The first blow of the hour, and not of the quarters, indicates the hour; the other quarters begin at their right times.

The large bells of Europe are now all that I have to speak of. I have already given at page 402 the particulars of the largest ringing peals in England, of which Exeter alone has a tenor above 3 tons. I must add that I neither vouch for the completeness nor the accuracy of the following list; the foreign bells are taken from Otte's book which I mentioned before, in some cases corrected by private information, which I have got from friends of my own who have measured some of

the bells, or from architects abroad who have been kind enough to send figured sections and dimensions of them. Some of the figures given here cannot possibly be accurate, but I do not know what to substitute for them. For instance, without going to the foreign bells, it is impossible that a bell of the size, note, and thickness of Peter of Exeter (of which I have a full sized section) can weigh anything like $5\frac{1}{2}$ tons, which is its reputed weight: I do not believe it is 5. Moreover it is evident that Otte uses different measures of length, and probably of weight also, for bells in different countries. For he puts down the Erfurt bell as only 8 ft. 3 in., and the Paris one as 8 ft., and Montreal 8 ft. 7 in.; whereas I know from two independent sets of measures and sections which I have, that the Paris bell is exactly the same size as Montreal, and Erfurt half an inch wider.

It is evident too that either the weight given for the bell at Sens is too great, or the size too little: from these specimens I should rather suppose the latter. The measures I have given may be relied upon, I think, for the bells at Moscow, Cologne, Rome, and Malta, besides Erfurt, Paris, and the English ones, including Montreal; but there is nothing more than reputation by way of authority for any of the weights, except of the modern English bells and old Tom of Lincoln, which was broken up in 1835 to be recast; and the evident exaggeration of the Exeter one is a warning against accepting these traditions too implicitly. Even the diameter of the St. Paul's bell figures still in many books as 9 feet, instead of 6 ft. 9 in.

I give the weights of the two great Russian bells by

calculation from their size and thickness, which is easily done, from their similarity to the Westminster pattern. I have seen even a larger weight than 8 cwt. given for the clapper of the Paris bell; but the 8 cwt. agrees pretty well with the drawing; but if the drawing I have of the Erfurt clapper is right it cannot be so heavy as Otte gives it. Our clappers are of a better shape than the foreign ones, though generally too light.

I have no doubt that some of these bells are bad ones, or they would have a greater reputation than they have. The Erfurt bell is the most famous of all the very large ones, and probably that of Paris next, though there are two opinions about that; the Cologne and Lucerne bells I have heard well spoken of. We have ample proof at home, at York, St. Paul's, and Oxford, that large bells may be thought not worth ringing after costing a great sum of money, or may sound no distinct note, or may be supposed to be cracked because they are so bad. I am told that the bell of St. Peter's at Rome sounds as ill as it ought to do from its extremely bad shape; I have a model of it, and it is loaded also with ornaments in high relief, which are sure to injure the sound; but the shape is such that it is of very little consequence what the decoration is. The Westminster bells are all rather sharp of the notes here indicated; according to the proposed universal pitch, in which A has 870 vibrations in a second; and so is the Canterbury bell.

Great Bells of	Date.	Diameter.		Weight.		Thickness.	Note.	Clapper or Hammer.
		ft	in.	tns	cwt	in.		
Moscow (piece broken out)	1734	22	8	220		23		Bell / 33
Another	1817	18	0	110		18	...	do.
Three others	...	...		16 to 31		...	...	
Novogorod	...	...		31	0			
Rouen (destroyed)	...	11	0	17	17			
Olmutz	...	...		17	18			cwt.
Vienna	1711	9	10	17	14	...	...	15
Westminster	1857	9	0	13	11	8¼	E	7
Sens		8	7	15	0			
Erfurt	1497	8	7½	13	15	7½	...	10?
Paris, Notre Dame	1680	8	7	12	16	7½	...	8
Montreal	1847	8	7	12	15	8½	F	413 lbs.
Magdeburg	1702	7	10	13	0			
Schaffhausen	1486	...		11	10			
Cologne	1448	7	11	11	3	...	G	
Breslaw	1507	...		11	0			
Amiens	1748	...		11	8			
York	1845	8	4	10	15	8⅝ / 7⅞	F sharp	405
Rheims	1570	...		10	9			
Vienna (another)	1558	...		10	8			
Bruges	1680	..		10	5	...	G	
Lyons	...	...		10	0			
Marseilles	...	...		8	19			
Gorlitz	1516	...		8	5			
Rome, St. Peter's	1786	7	4	8	0			
Schneeberg	...	7	6	7	19			
Nuremberg	1392	...		7	16			
Oxford	1680	7	0	7	12	6½	5 notes	80
Lucerne	1636	...		7	12			
Halberstadt	1457	...		7	10			
Antwerp	...	....		7	3			
Brussels	...	...		7	1			
Halle	1480	...		6	10			

Great Bells of	Date.	Diameter.		Weight.		Thickness.	Note.	Clapper or Hammer.
		ft.	in	tns	cwt	in.		lbs.
Munich	1493	7	3	6	5			
Dantzic	1453	...		6	1			
Cologne (another)	1449	...		6	0			
Ratisbon	1325	...		5	16			
Magdeburg (anoth.)	1690	6	2?	5	15			
Leipsic	1634	...		5	14			
Breslaw	1721	...		5	13			
Brunn	1515	...		5	10			
Ghent	...	...		5	10			
Rodiz	1841	...		5	10			
Chalons	...	...		5	9			
Lincoln	1835	6	$10\frac{1}{2}$	5	8	6	A	150
Mariazell	1830	...		5	5			
St. Paul's, London	1716	6	$9\frac{1}{2}$	5	4	...	A & C sh.	180
Dresden	1787	...		5	2			
Rouen	...	6	$4\frac{1}{2}$	5	9?			
Exeter (Peter)	1675	6	4	5	0	5	A	70
Frankfort	1371	6	4	5	0			
Old Lincoln	1610	6	$3\frac{1}{2}$	4	18			
Leeds Town Hall	1859	6	2	4	1	6	B	200
Valetta, Malta	[illegible]	6	1				B flat.	
Amiens (another)	1736	6	00	5	0?			
[illegible]	18..	...		4	0			
Westminster, 4th	1857	6	0	3	18	$5\frac{7}{8}$	B	175
,, third	1858	4	6	1	$13\frac{1}{2}$	$4\frac{1}{8}$	E	80
,, second	1857	4	0	1	6	$3\frac{7}{8}$	F sharp	60
,, first	1857	3	9	1	1	$3\frac{3}{4}$	G sharp	56
Exeter tenor	1676	5	$11\frac{1}{2}$	3	7	5	B flat.	
Hôtel de Ville, Paris, clock-bell	...	...		3	10	...	...	145
Canterbury	[illegible]	6	9	3	10	$5\frac{1}{4}$	C	
Gloucester	14...	5	$8\frac{1}{2}$	3	5	...	C	

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ERRATA.

Page [illegible]9, line 5, *for* S_1, S, S, *read*

,, 115, line 5, *for* $\frac{P_p}{M}$ *read* $\frac{I_p}{M_l}$

,, 189, line 5, *for* 3rd *read* 4th.

,, 189, line 6, *for* 5th *read* 6th.

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